James F. Baldwin Esq.
with the respects of
M Wyman.

A PRACTICAL TREATISE ON VENTILATION:

BY

MORRILL WYMAN.

"PLURES OCCIDIT AER QUAM GLADIUS."

CAMBRIDGE:
METCALF AND COMPANY.
1846.

CAMBRIDGE:

METCALF AND COMPANY,

PRINTERS TO THE UNIVERSITY.

TO

DANIEL TREADWELL, A. M.,

THIS VOLUME IS,

WITH SINCERE RESPECT,

INSCRIBED BY HIS FRIEND,

THE AUTHOR.

PREFACE.

My object in printing the following pages is to present to the public those principles of ventilation which have been, for the most part successfully, applied in Europe, and also to offer such suggestions and arrangements as seem best fitted to answer the desired purpose in this climate.

It must not be supposed, however, that any system of ventilation can be carried into successful operation, unless it receives the attention of some competent persons. The circumstances, for instance, under which members of the legislature and of the bar are placed, are constantly varying with the number of persons present, and the external temperature; if the quantity of air and its temperature are not made to vary accordingly, nothing like a comfortable

and healthy atmosphere can be preserved. No system can be made self-acting.*

I hardly need mention, that it is a matter of impossibility that the same ventilating arrangements should be applicable to entirely different structures,— to large public halls and to dwelling-houses; and yet, in the view of some, it would appear that there is but one system, and that this, whether applicable or not, must be adopted, whenever ventilation is required.

The plan which I have followed in treating the subject has been,—

First, to describe the laws and properties of

---

* I have been led to make these remarks from seeing the following paragraph in the London Times of November 3, 1845: —

" *Centre Criminal Court.* — The counsel hoped to be excused, if he suggested to his Lordship that he should use his influence with the city authorities to relieve the bar, and indeed every person sitting in the body of the Court, from the intolerable annoyance which arose from the operation of Dr. Reid's system of ventilation. At one moment they were exposed to a volume of hot air which was insupportable, and at another to blasts of cold wind blown into the Court by workmen engaged outside. He could assure the Court that it was almost killing his brethren of the bar, two of whom were now suffering in consequence of their attendance in Court, and consequent exposure to those varied currents, during the present session."

Now for the particular arrangements in this single case I cannot answer, and what is meant by *Dr. Reid's system of ventilation* I cannot say; it is clear, however, from the statement, that there was sufficient power and sufficient range of temperature, but they were not properly regulated. To whom the duty of regulating them belonged, it is easy to see.

gases generally; especially the law of their diffusion, so important in its influence upon ventilation.

Secondly, the chemical and physical properties of the atmosphere.

Thirdly, the processes by which atmospheric air may become vitiated; particularly the processes of respiration and combustion, and the nature of the gases produced by them.

Fourthly, the means by which impurities, whether chemical or mechanical, may be removed from atmospheric air.

Fifthly, the principles of the movements induced in air by heat, especially those occurring in apartments and in chimneys.

Sixthly, the moving power best adapted to ventilation, and the quantity and qualities of the air which should be supplied.

Lastly, the mechanical arrangements best adapted to effect the ventilation of the various structures to which they are applied.

It was my intention to have added a second part, on the Art of Warming; but the size which the volume has already reached renders it necessary to postpone that portion of the work.

Cambridge, June 10, 1846.

CONTENTS.

INTRODUCTION.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

VITIATED AIR.

CHAPTER VII.

OF PREVENTING AND REMOVING IMPURITIES OF THE AIR.

CHAPTER VIII.

MOVEMENTS INDUCED IN ATMOSPHERIC AIR BY HEAT.

CHAPTER IX.

OF THE CURRENTS PRODUCED IN ROOMS BY HEAT, AND OF THE PRINCIPLES OF VENTILATION.

CHAPTER X.

MOVING POWER FOR VENTILATION.

CHAPTER XI.

QUANTITY OF AIR REQUIRED FOR VENTILATION.

CHAPTER XII.

OF THE VENTILATION OF PUBLIC BUILDINGS.

CHAPTER XIII.

VENTILATION OF PRISONS AND HOSPITALS.

CHAPTER XIV.

VENTILATION OF DWELLING-HOUSES.

CHAPTER XV.

VENTILATION OF SHIPS.

CHAPTER XVI.

ANATOMICAL ROOMS.

CHAPTER XVII.

CHIMNEY-TOPS, TURN-CAPS, AND VENTILATORS.

CHAPTER XVIII.

DRAINAGE.

APPENDIX.

PRACTICAL TREATISE.

INTRODUCTION.

General Considerations with Regard to the Atmosphere. — Its Analysis. — Air the Origin of all organized Bodies. — Analysis of Plants. — They decompose Carbonic Acid and liberate Oxygen. — Animals consume Oxygen and liberate Carbonic Acid. — Balance of Atmosphere preserved. — Influence of Diffusion of Gases and of Winds.

ORGANIC CHEMISTRY has taught us that plants and animals, all organized bodies, not only depend upon the AIR for the continuance of life, but that it is the origin of the materials of which these bodies are composed. A knowledge of its constituents and of the changes it undergoes in these forms, so different from that in which we are accustomed to find it, cannot but be important; for a change in its sensible properties, or even in the proportions of its elements, must have an influence upon its dependents. As it is the object of *ventilation* to afford a constant supply of pure air, and remove that which has been deteriorated, it should be our first care to understand the properties of pure air, and the means by which its purity is preserved.

A portion of mercury heated to nearly its boiling point in atmospheric air confined in a vessel, and agitated with it, is changed in its appearance, and a part of the air disappears. On removing the mercury, it will be found to have become heavier in proportion to the weight of the air which has disappeared. If it is heated in a close vessel, to which is attached a proper apparatus for collecting any gases which may escape, the metal will regain its original weight, and give up a portion of gas exactly equivalent to that which was lost by the confined air. This gas is called *oxygen ;* it possesses certain properties, — among others, that of supporting combustion and animal life. A portion of water in which lime has been dissolved being added to the air first mentioned, and agitated with it, will become turbid, and a white powder will be deposited, and the air will again have suffered a slight diminution of weight. This powder, when treated like the mercury, will also give up a portion, but a very much smaller portion, of gas, which will be equal in weight to that lost by the air. This second gas is called *carbonic acid ;* it is heavier than common air, and can be poured from one vessel into another like water ; it neither supports combustion nor animal life. If we now examine the remaining air, we shall find, that, like carbonic acid, it supports neither combustion nor animal life, and that it is lighter than common air ; this is *nitrogen* gas. Oxygen and nitrogen have never been decomposed ; they are considered elementary bodies.

By this supposed process we have discovered that

the air we breathe is composed of three gases, oxygen, nitrogen, and carbonic acid. Its analysis has occupied the attention of the ablest chemists, and now that accurate modes have been adopted their results are nearly identical, namely: oxygen, by weight, 23.02 parts ; nitrogen, 76.98 ; or by volume, 208 parts of the first to 792 of the second, the volume of carbonic acid varying between four and six ten-thousandths. Besides these gases, atmospheric air contains a quantity of water in the form of vapor, its amount being determined by the temperature and other circumstances ; it is the condensation of this vapor which constitutes rain.

Carbonic acid and water may be further decomposed. The former may be shown to consist of two substances, — oxygen gas, and a solid, composing the principal part of charcoal and almost the whole of anthracite coal, called *carbon*. Water may also be shown to consist of oxygen gas, and of another very light gas called *hydrogen*, which is inflammable, but does not support combustion.

We have said that organic chemistry points out the air as the origin of all organized bodies. A careful analysis of the leaf or stem of a plant has demonstrated, that, when the earthy matter, which serves as a skeleton or framework on which the living matter may be laid, is removed, the remainder consists for the most part of but three constituents, carbon, oxygen, and hydrogen ; these three are essential to its existence, — a fourth, nitrogen, being necessary for certain processes only. But all these gases, we have seen, exist in the air ; it is not

impossible, then, strange as it may appear, that plants may have been derived from it. But this has been put beyond doubt by actual experiment. Peas have been sown in flint-sand, which had been heated to redness to deprive it of organic matter, — have been watered with distilled water only, and the windows of the room kept closed, — and yet at the end of ninety-nine days they had more than trebled their weight. Whence could this organic matter have been obtained but from the air? The air-plant will flourish, although it has no connection with the ground, adhering to the branch of a tree by its slight roots for support merely. Although it is thus clear that the smaller and apparently less useful plants may and do obtain their elements from the air, and during their decay return a portion of them to it, leaving the rest to form a vegetable mould, the larger plants do not derive their constituents so directly from the same source. To flourish and yield their full crop, they require a soil into which they may strike their roots, and this is afforded by the plants just mentioned. It is probable that these last play, in a degree, the part which all edible plants do to animals, — that they prepare organic elements for their support. But the air is no less the origin of the larger and more productive plants because it has passed through the smaller in its progress to them. The carbon which forms so large a part of all trees is undoubtedly derived from the atmosphere, absorbed directly by the leaves, or, indirectly, through the medium of rain-water applied to the roots. Still, the question arises, How is this gas

decomposed and its carbon appropriated ? for it is known to chemists to be decomposed only by strong heat or active reagents. The mode of decomposition we cannot explain, but we know that plants exposed to the sun-light have this wonderful property. The green parts of plants have the property of absorbing so completely the chemical rays of the sun-light, that they are never reproduced in the Daguerrian landscape. In the leaves, the watery portion of the sap is evaporated and the nutritive parts concentrated, the carbonic acid decomposed and its oxygen liberated. We see, then, that the constant action of plants, during their whole period of growth, is in the production of organized matter and the liberation of oxygen.

If we now turn to the animal kingdom, our attention is immediately arrested by the fact, that, unlike plants, animals produce no organized substances, but consume them.* The tissues of animals, widely as they differ in appearance, are discovered upon analysis to consist mainly of but four elements, oxygen, hydrogen, carbon, and nitrogen, the last being the only one which does not necessarily exist in all plants. During this consumption or combustion of organized matter, animals are constantly returning to the atmosphere, by respiration, carbon in the form of carbonic acid, and hydrogen in the form of aqueous vapor. The various tissues are as completely oxidized by their union with the oxygen of the air in this

---

* See Appendix, No. I.

process, as they would have been, had the combination taken place with the evolution of light and intense heat.

Hence we see that the vegetable kingdom is the great laboratory of organic life, forming not only what is required for its own existence, but that which goes to the support of all animated nature. From this source is derived the animal structure of the *herbivora*, who in their turn nourish the *carnivora;* and these last, sooner or later, by respiration during life or decomposition after death, restore to the air all they have received from it. Plants produce, animals destroy; each eliminates what the other consumes.

The mutual influence of animal and vegetable life is well illustrated by the following experiment. Into a glass vessel filled with water put a sprig of a plant and a fish; let the vessel be tightly corked and placed in the sun. The plant, under the influence of solar light, will soon commence the process of liberating oxygen; this, being absorbed by the water, is respired by the fish, which in its turn gives out carbonic acid to be decomposed by the plant. Remove the vessel from the sun-light, the plant will cease to give out oxygen, and the fish soon languish, and revive when replaced in the light. The moving power in this beautiful system is the solar light. The balance is thus preserved, and the atmosphere, even if of limited extent, cannot be sensibly changed through all time.

It is not intended to intimate that it is in the removal of carbonic acid from the atmosphere that plants are

most essential to animals, — the supply of organic matter ready for assimilation is of more immediate importance than this, — but to show that their influence is mutually conservative, preventing that change in the constituents of the atmosphere which would *eventually* be fatal to organic life.*

The following calculation, by Dumas, will show, however, that the danger of any such event would be by no means imminent, with the present extent of atmosphere. "The air which surrounds us weighs as much as 581,000 cubes of copper, 3,273 feet by the side; its oxygen equals in weight 134,000 of these same cubes. Supposing the earth peopled with a thousand million men, and animals equivalent to three thousand million of men, they would not together consume in a century a weight of oxygen equivalent to sixteen of these cubes of copper, while the air contains 134,000 of them. It would require 10,000 years for this number of men to produce a sensible effect on the eudiometer of Volta, even supposing all vegetable life annihilated!"

It may be supposed, however, that, where animals are assembled in great numbers, and the processes of combustion, which also produce carbonic acid, are going on rapidly, uninfluenced by vegetation, as in large cities, carbonic acid may accumulate and become injurious to life. Delicate analysis detects a slight difference in this respect between the air of a dense city and that near

* For an excellent account of the reciprocal influence of plants and animals, see Professor Asa Gray's Botanical Text-Book.

the luxurious vegetation of the country ; it would undoubtedly be much greater, were it not for the remarkable property which all gases possess of diffusing themselves through each other's masses, more slowly it is true, but with as much certainty, as they rush into a vacuum. The influence of winds, also, sweeping through properly arranged streets, under ordinary circumstances, effectually prevents any such accumulation. The air at the equator and between the tropics, expanded by heat, and urged by the colder atmosphere pressing from the poles towards the same points, rises and diffuses itself through the upper air, and effectually prevents all stagnation.

We have here indicated the means employed for the *ventilation of the globe*, constantly acting according to fixed, and, for the most part, well understood laws. It is by attention to these same laws that we may hope to establish the aeration of our dwellings upon correct principles, and prevent the injurious effects which must necessarily follow from their neglect.

CHAPTER I.

The Properties of Gases. — Elastic. — Movable. — Weight of Gases. — Table of Specific Gravity of Gases and Vapors. — Diffusion of Gases. — Mr. Dalton's Explanation of Diffusion. — Professor Graham's Experiments. — Law of Diffusion. — Its Importance in the Practice of Ventilation. — Expansion of Gases. — Their Absorption by Water and Charcoal. — Table of Absorption by Charcoal.

The various aeriform fluids are divided into *vapors* and *gases ;* steam is the most familiar example of the first, and atmospheric air of the second of these divisions. When water is heated above the temperature of 212° Fah., it takes the form of steam, and follows all the laws of gases, and becomes like them perfectly elastic, compressible, and movable. This last property is such, that, however slightly we diminish the pressure upon any one portion of a gas, that which surrounds it instantly rushes in to restore the equilibrium, and it thus becomes the most delicate balance conceivable. Although gases oppose so little resistance to bodies moving through them, if their particles are brought within a certain distance of each other, they exhibit all the properties of solids. One of them, carbonic acid, under the influence of pressure and great cold (the cold being produced by the expansion which a portion of the gas in the liquid state undergoes when relieved of the pressure), has been made to assume the form of a white, friable solid, not unlike chalk or magnesia. Other gases become liquid

under different pressures ; and it is supposed by geologists that atmospheric air, although it has as yet never been reduced by art, may nevertheless be liquid in cavities subjected to immense pressure in the lower strata of the globe ; it has also been imagined that the whole globe itself, under the influence of heat, once existed in the form of vapor or *fire-mist.* Hence we see that vapors and gases differ in degree only, and have reference to the temperature and pressure to which they are ordinarily subjected.

Gases are perfectly elastic bodies. The elasticity of solids is within certain limits only ; the best springs of locomotive engines and carriages seem capable of suffering but a limited number of bendings before they break. Air remains constantly elastic ; it has been shut up for years in the air-vessel of a hydraulic engine, and still exhibited this property as perfectly as at first. Boyle, and afterwards Mariotte, investigated the law of the elasticity of gases, and demonstrated that the volume is inversely as the pressure. As we remove the pressure, they constantly expand, and always fill completely the vessel in which they are contained.

Weight of Gases. — It has been demonstrated that a flask from which the air has been exhausted weighs less than when full. The weighing of gases is a nice operation, requiring great care that the gas be pure, dry, and under a known pressure and temperature. Philosophers have assumed as a standard pressure 30 inches of the barometer, and a temperature of 60° Fah. In

the following table we have the weight of 100 cubic inches of several vapors and gases, with their specific gravity or density, air being considered as 1.

Specific Gravity of Gases and Vapors.

	Cubic Inches.	Weight in Grains.	Specific Gravity. Air 1.	Weight of 1 Cubic Ft. in Grs.
Atmospheric air,	100	31.0117	1.	535.68
Oxygen,	100	34.109	1.1025	589 2
Nitrogen,	100	30.166	0.9722	521 8
Hydrogen,	100	2.137	0.0690	36.29
Vapor of water at 60°,	100	0.356	0.0115	6.04
Vapor of water at 212°,	100	19.22	0.6240	331.7
Carbonic acid,	100	47.262	1.5239	815.6
Carbonic oxide,	100	30.207	0 9727	521.8
Vapor of alcohol,	100	49.618	1.6012	857.
Vapor of sulphuric ether,	100	80.010	2.5822	1382.4
Carburetted hydrogen,	100	17 45	0.558	298.5

The pressure which gases exert upon bodies at the surface of the earth depends upon their weight, and as hydrogen is but one sixteenth the weight of common air, an atmosphere of the same height will press with a force of one-sixteenth only. Hence, a man would weigh more, and require a greater force to transmit himself from place to place, in an atmosphere of hydrogen, than in the present atmosphere. The velocity with which air enters a vacuum depends upon the height of the column of air above it, and consequently varies with its density. It is obvious, that, as the density depends upon the height of the incumbent column, it must be constantly diminishing as we ascend, until we arrive at a point at which there will be but a single layer of particles, and the two forces of weight, or attraction of gravitation, and elasticity of the air, be in exact equilibrium. Hence, the height of any point may be ascer-

tained by weighing the superincumbent column of air against a column of mercury, — the higher the point, the shorter will be the column of mercury; it is thus that heights are measured by the barometer.

Diffusion of Gases. — The discovery of this law, to which we have before referred, has done much to establish the true principles of ventilation. Aeriform bodies possess the property of diffusing themselves through each other's masses to an unlimited extent; there is no point at which they become saturated. Mr. Dalton filled two cylindrical vessels, the one with carbonic acid, and the other with hydrogen; the latter was placed perpendicularly over the former, and the two connected together by means of a small tube two or three feet long. In the course of a few hours, hydrogen was detected in the lower vessel, and carbonic acid in the upper; after a still longer time, these gases were found perfectly and equally mixed.

If we examine the table of the specific gravity of gases, above given, we shall find that carbonic acid is more than twenty times the weight of hydrogen; consequently the change of place was produced in opposition to the laws of gravity.

This property belongs to all gases and vapors. If water be placed in a vessel of dry air, evaporation will go on as in a vacuum, but more slowly, the air acting as a mechanical obstacle; and the tension or elastic force of the vapor will be precisely the same in the one case as in the other. A given volume of air will contain the

same weight of vapor as a vacuum of the same dimensions.

Mr. Dalton, in his explanation of these phenomena, supposes that the atoms of one gas, although highly repulsive to each other, do not repel those of other gases; that, in the case of carbonic acid and hydrogen, each allows the atoms of the other to insinuate themselves between its own atoms, and establish a perfectly equal mixture. "One gas," he says, "acts as a vacuum with respect to the other." By this expression, however, he did not mean that one gas flowed into another with the same velocity as into a vacuum, — for the atoms, offer a mechanical impediment to diffusion, — but that, although more slowly, the final result would be the same. This we shall see, farther, has an important bearing upon the perfect mixture of gases in combustion.

When a portion of gas is confined in a glass vessel having a crack in its side, the gas after a time will have diffused itself into the air, and the air will have found its way through the same opening into the gas. The quantities which have thus passed in a given time will bear a certain relation to the specific gravities of the two gases. The diffusion depends in no degree on the size of the aperture, but each gas has a diffusiveness peculiar to itself. Professor Graham was enabled to determine the law of diffusion with great exactness by means of a tube closed at one end with plaster of Paris. By filling this tube, over water, with the gas to be experimented upon, and allowing it to remain with its lower or open end

immersed in the water, the diffusion immediately commenced through the porous stopper, and the water was seen rising in the tube. From experiments carefully conducted with this instrument, or *diffusion tube*, as it is called, Professor Graham discovered that "the diffusion or spontaneous intermixture of two gases in contact is effected by interchange in position of indefinitely small volumes of the gases, which volumes are not necessarily of equal magnitude, being, in the case of each gas, inversely proportional to the square root of the density of that gas." Thus, the density of the air being 1, its diffusiveness will be 1 also; and knowing the density of other gases compared with it, we may deduce their rate of diffusion.

The following figures indicate the densities of some of the gases, with their diffusiveness, according to this law.*

Hydrogen	$\sqrt{0.069} = 0.2627$
Oxygen	$\sqrt{1.105} = 1.052$
Nitrogen	$\sqrt{0.972} = 0.986$
Steam	$\sqrt{0.620} = 0.788$

$0.2627 : 1 :: 1 : 3.807 =$	Diffusiveness of	hydrogen.
$1.052 : 1 :: 1 : 0.9505 =$	"	oxygen.
$0.986 : 1 :: 1 : 1.014 =$	"	nitrogen.
$0.788 : 1 :: 1 : 1.269 =$	"	steam.

The results of these experiments coincide so exactly

* Daniel's Introduction to Chemical Philosophy, p. 75.

with the law, that the density of the gas may be determined by experimentally determining its diffusion.*

As a further confirmation of Dalton's theory, it may be remarked, that all gases rush into a vacuum with a velocity also inversely proportional to the square roots of their densities. It has been determined, that, if our atmosphere be considered as of the same density throughout, *homogeneous*, and 27,335 feet in height, the velocity with which it enters a vacuum will be 1,338 feet in a second of time; the velocity of diffusion is, as we have remarked, much less.

That this interchange and mixture are the result of affinity or chemical action is disproved by the fact, that it takes place between gases which have no such affinity. Carbonic acid cannot be made to unite with either hydrogen, oxygen, or nitrogen; besides which, it is to be observed, that, when volumes of two different gases are brought in contact, each diffuses itself through the other, occupying the space of the sum of the two, and that without any increase of temperature. When oxygen and nitrogen gases are mixed together in the proportion of 1 to 4, the mixture occupies exactly the space of five volumes of either, and is, according to all the tests which chemistry can apply, pure atmospheric air.

We have explained this law the more fully, that a knowledge of it may prevent mistakes which are serious, in forming a plan for efficient ventilation. We are told,

* If d denotes the diffusiveness, and g the specific gravity, we have $d=\frac{1}{\sqrt{g}}$ according to the law of diffusion; hence we obtain $g=\frac{1}{d^2}$.

in a work on Warming and Ventilating, "that the ammonia and aqueous vapor invariably ascend towards the ceiling ; while the dense carbonic acid will find its way out at the doors and lower apertures, or will remain stagnant in the passages, unless subject to a current of atmospheric air."* In a Report on Schoolhouses it is said, "The poisonous parts are called carbonic acid. They are heavier than the common air, and, as the lungs throw them out at the lips, their tendency is to fall towards the ground, and, if there were no currents of the air, would do so. Were these different portions of the air, as they come from the lungs, of different colors, we should, in a perfectly still atmosphere, see the stream divided, part of it falling, and part ascending. A circulation of air, however, produced out of doors by differences of temperature, and in our apartments by the motion of the occupants, and by other causes, keeps the poisonous parts of the air, to some extent, mingled with the rest of it."† Farther on we are old, "If there be but little motion in a room, the poisonous part of the air will settle towards the floor as soon as it is cast from the lungs, while the other part, being raised almost to a blood heat in the lungs, will rise to the ceiling. In the ceiling, therefore, should be an aperture for its escape. The carbonic acid will tend to flow out under the door, or when it is opened." In the Report of the Design

* The Theory and Practice of Warming and Ventilating, by an Engineer, p. 113.

† Report of the Secretary of the Board of Education on Schoolhouses, pp. 9, 14.

for a Lunatic Asylum, the author remarks, if the register for admitting hot air is high enough to avoid certain difficulties he has mentioned, "the hot air will not be well disseminated, the hottest portion will constitute a stratum next the ceiling, while that at the floor is *sour* and *carbonic*." Now, if the law, as stated by Dr. Dalton, that "one gas acts as a *vacuum* with respect to another," be true, neither statement can be correct; if they were correct, we should certainly provide a means of escape separately for the gases, according to their density. Ample provision is made for diffusion; the expired gases, with the aqueous vapor, are lighter than the surrounding air; they rise to the ceiling, and, if they do not escape, become so completely mixed with it, that they never again separate.* It is true that carbonic acid generated in large quantities from low places, where it is retained as in a basin, — in mines, in certain grottos, in wells, and after it becomes cold when generated in close rooms by the combustion of charcoal, — accumulates on the floor; but the conditions are so unlike the cases above mentioned, that no analogy can be maintained, and we are aware of no experiments which would support them.

We can hardly estimate the importance of this beautiful law. Animals and vegetables, as we have already shown, are constantly pouring out certain gases, each essential to the life and growth of the other, and yet, if these gases were allowed to stagnate where they are formed, they would not only injure, but destroy, both

* See Appendix, No. II.

kingdoms. By this law, these poisons are diffused throughout space, and vital air rushes in to supply their place ; it is only by the most delicate analysis, and for a short time, that any differences in the constitution of the atmosphere can be detected. At the level of the sea, and at the highest point to which man has ascended, it is invariably the same. Yet it is a mixture, and requires no power to decompose it ; every substance having an affinity for oxygen removes it as readily as though the nitrogen were altogether absent. Even water effects a separation of its elements, for the air expelled from it by boiling contains more than 21 per cent. of oxygen. Further on, when speaking of respiration, we shall see still more the peculiar adaptation of this law to the animal economy.*

Expansion of Gases. — Unlike solids, gases expand equally for an equal increase of temperature as measured by a thermometer. Gay-Lussac showed that 100 measures of atmospheric air, heated from the freezing to the boiling point, became 137.5 measures ; consequently the increase for 180° F. is $\frac{37.5}{100}$ of its bulk ; dividing this quantity by 180, we find that a given quantity of dry air expands $\frac{1}{480}$ *of the volume it occupied at* 32° for every degree of Fahrenheit. New experiments have been made by Rudberg, within a few years, giving $\frac{1}{491}$ as the rate of expansion for 1° F. ; and these results are confirmed by Regnault. This last number may be adopted as the true

* The porosity of our clothing allows the same interchange of gases to go on in contact with our persons, and to conduce to the constant removal of noxious exhalations and aqueous vapor.

increment; its equivalent in decimals is 0.002036; for 1° Centigrade, it is 0.00365.

If we wish to ascertain the volume which 100 cubic inches of a gas at 40° would occupy at 80°, we must remember that it does not expand $\frac{1}{491}$ of its bulk at 40° for each degree, but $\frac{1}{491}$ of its bulk at 32°. Now 491 parts of air at 32° become 492 at 33°, 493 at 34°, and so on; hence we can institute a proportion between the volume at 40° and that at 80°.*

Vol. at 40.		Vol. at 80.		Cub. Inch.		Cub. Inch.
491 + 8	:	491 + 48	::	100	:	108.

Absorption of Gases.—Gases are absorbed by different substances, and in some cases the force with which they are drawn to them is greater than the mutual repulsion of the gaseous particles themselves. When a piece of metallic platinum is made perfectly clean and bright, and brought in contact with oxygen and hydrogen, the adhesion of these gases to the metal is apparently such as to overcome their ordinarily repulsive properties, to bring them within the sphere of chemical action, and produce rapid combustion with the evolution of light and heat.

Gases are also dissolved in water, as is the case with atmospheric air; it is to this property that the inhabitants of the ocean owe the oxygen which supports their existence. The quantity thus held in solution is in proportion to the pressure. Carbonic acid is dissolved in an equal bulk of water under the ordinary pressure of the

---

* See Appendix, No. III.

atmosphere ; by doubling the pressure another volume may be taken up, and so on. It is in this way that the soda water of the shops is kept ready for use under mechanical pressure. On the tops of high mountains, the pressure on the surface of the water is obviously less, and less atmospheric air will be dissolved ; it may be owing to this cause that fish are not found to inhabit the ponds of very elevated regions.

Charcoal possesses the property of absorbing some gases to a great extent, as may be seen by the following table, in which the numbers indicate the volumes of gases absorbed, that of the charcoal being taken as unity.*

Absorption of Gases by Charcoal.

Ammonia	90	Bi-carb. hydrogen	35.
Muriatic acid	85	Carbonic oxide	9.4
Sulphureous acid	65	Oxygen	9.2
Sulphuretted hydrogen	55	Nitrogen	7 5
Nitrous oxide	40	Carbur. hydrogen	5.
Carbonic acid	35	Hydrogen	1.7

* Daniel's Introduction, p. 60.

CHAPTER II.

The Atmosphere. — Its Chemical Properties. — Proportion of its Constituents. — Oxygen, its Importance and Properties. — Influence on Animal Ecomony in Health and Disease. — Nitrogen, Uniformity of its Presence in Animal Tissues. — Combinations of Oxygen and Nitrogen. — Carbonic Acid. — Irrespirable.

The whole practice of ventilation depends upon the changes and movements which we may be able to produce in the atmosphere; consequently, a knowledge of its properties is essential to insure a rational and effective system. Some of these properties we shall proceed to point out.

We have already stated that the atmosphere is a true mixture (this, at least, is the present opinion of the most distinguished chemists), and have mentioned the great advantages which flow from the ready separation that may be produced between its component parts.

By weight, air contains 23.02 parts of oxygen, and 76.98 of nitrogen; by volume, 208 of the first, and 792 of the second. Besides these, there is a portion of carbonic acid, varying in amount from $\frac{4}{10000}$ to $\frac{6}{10000}$, whether taken in the city or open plain; ordinarily $\frac{4}{10000}$. Finally, it holds an almost inappreciable portion of light carburetted hydrogen gas, or gas of marshes, which is formed in stagnant pools during the decomposition of vegetable matter, and is continually escaping from their surface. The

proportions of the first two gases are invariable. Analyses have, for a series of years, been frequently made, without detecting any differences which could not be attributed to errors of analyzers.*

Oxygen. — Atmospheric air depends upon this gas for its vivifying influence, and for its power of supporting combustion. It unites with nearly every substance upon the earth, with various degrees of energy and rapidity; if rapidly, producing flame; if more slowly, those changes upon metals known as oxidization or rusting. A piece of wood or charcoal, having upon it but the slightest spark, when plunged into this gas bursts into flame; and phosphorus burns with such intensity of light, that the eye can with difficulty support it. The first conditions of animal life are the introduction of nutritious matter and oxygen into the system. Man, at every moment of his life, consumes oxygen; nearly two pounds in the twenty-four hours. In the body it unites with the various tissues, or with articles of food, and is exhaled as carbonic acid in combination with their elements. This process of combustion, as it may be called, goes on constantly; and if the animal does not repair its losses by food, its weight diminishes, the tissues are consumed, and it dies of starvation.

Various experiments have been made on the respiration of oxygen undiluted with nitrogen. The results do not exactly coincide; but, although it appears that this gas will support life longer than an equal quantity of air,

---

* Appendix, No. IV.

when continued, there is a general tendency to inflammation, which sooner or later proves fatal. According to the experiments of Broughton upon rabbits, no inconvenience is at first perceived ; but, after the interval of an hour or more, the circulation and respiration become very rapid, and the system in general is highly excited. Symptoms of debility subsequently ensue, followed by insensibility; and death occurs in six, ten, or twelve hours. On examination, after death, the blood is found highly florid in every part of the body, and the the heart acts strongly, even after breathing has ceased.*

The respiration of oxygen was at one time proposed as a remedy for disease. It was supposed, that, as in consumption, a part only of the lungs were capable of performing their functions ; that it was probably want of oxygen which produced death, and if the air were richer in this gas, the final result, the introduction of oxygen, would be accomplished, and the patient restored. Chapal relates that a man was induced to make the trial who was in confirmed consumption, having extreme weakness, profuse sweats, and every symptom, in short, which indicated the near approach of death. One of his friends put him upon a course of vital air. He respired it with delight, and asked for it with all the eagerness of an infant at the breast ; during the respiration, he felt a comfortable glow distribute itself through all his limbs. His strength increased with great rapidity, and in six weeks

* Turner's Elements of Chemistry, edited by Liebig and Gregory, p. 188.

he was able to take long walks. But, after six months, he relapsed, and, being unable to obtain the vital air, died. M. Chaptal says, it inspires cheerfulness, renders the patient happy, and in desperate cases is certainly a most precious remedy, which can spread flowers in the pathway to the tomb, and prepare us, in the gentlest manner, for the last great change.

The enthusiastic Beddoes, in England, also made many experiments upon persons suffering under disease; the respiration of oxygen and other gases, for a time, worked wonders; but after further trials it fell into disuse, and has since been employed only by illiterate empirics.

Nitrogen. — The uses of this gas are in a great measure unknown. It has been supposed to act merely as a diluent to the oxygen. It will not support combustion nor animal life. There is no reason, however, to suppose that it acts as a poison, but it destroys by suffocation, or the exclusion of oxygen merely. When we consider that all the parts of animals which have a decided shape, or which form parts of organs, contain nitrogen, — no part of an organ which possesses motion and life is destitute of it, — and that, from late and careful experiments, it is proved that animals invariably exhale it, we cannot but wish for a more careful study of its nature and importance to the animal economy.

Oxygen and nitrogen, which, in the proportions forming atmospheric air, are so mild and important to the human system, in other proportions produce entirely different, and, in some instances, energetic substances,

the activity increasing in proportion to the quantity of oxygen, as we may see from the following table, in which the proportions are given in volumes.

	Nitrogen.	Oxygen.
Atmospheric air . .	100	20
Nitrous oxide . .	100	50
Nitric oxide . . .	100	100
Hypo-nitrous acid . .	100	150
Nitrous acid . . .	100	200
Nitric acid . . .	100	250

The first of these is known as exhilarating gas, which, when inhaled, produces a powerful excitement of the nervous system, a strong propensity to laughter, and a rapid flow of ideas, in many respects resembling the excitement from alcohol, but differing from it in not being usually followed by a state of depression. Nitric oxide is a gas, but is irrespirable, any attempts to inhale it being followed by a severe spasm of the upper part of the windpipe. All the other compounds are liquids, the two last powerfully corrosive, and the last known in the shops as *aquafortis*.

Carbonic Acid. — From the important part which this gas plays in the economy of nature, as we have already pointed out, it can by no means, in the proportions of $\frac{4}{10000}$ to $\frac{6}{10000}$, be considered as poisonous. When pure, it extinguishes flame, not by the absence of oxygen, but by exerting a positive influence upon it, as appears from the fact, that a candle cannot burn in a mixture of four parts of atmospheric air and one of carbonic acid; it also destroys life, acting as a narcotic upon the system. The narcotic effect is produced only when the gas is inhaled in

the diluted state ; when pure, it produces a spasm of the throat, which effectually prevents its entering the lungs. Although so poisonous when taken into the lungs, when drunk in solution as *soda-water*, it forms a pleasant and refreshing beverage.

CHAPTER III.

The Atmosphere.— Its Physical Properties.—Weight, its Amount on various Extents of Surface. — Density, the Law of its Diminution. — Table of Density. — Heat of Atmosphere. — Of Winds. — Sea and Land Breezes. — Velocity by Calculation. — Trade Winds. — Moisture. — Its Deposition. — Dew-Point. — Clouds. — Evaporation. — Latent Heat of Vapor. — Mode of ascertaining Dew-Point. — Hygrometer. — Electricity. — Its Development. — Daily Variation in Amount. — Influence on Animals.

THE surrounding medium performs the office of a universal solvent to the various effluvia which are constantly emanating from the surface of the earth, and the substances and beings by which it is covered. It contains a little of every thing capable of assuming the gaseous form; the odor of flowers, the minute *spores* or buds of the lower orders of plants, and particles of dust, are continually floating in it; each of the earths and metals has an odor of its own, and each contributes its share to the mixture. Yet these various substances form so minute a proportion of the atmosphere, that, except in certain localities and under peculiar circumstances, they cannot be detected.

Weight of the Atmosphere. — The pressure of the air sustains in the barometer a column of mercury of the average height of 29.82 inches. A column of air equal in length to the whole height of the atmosphere, and one of mercury of the height just mentioned, are of

equal weights ; consequently the whole atmosphere may be represented in weight by a layer of mercury extending over the whole surface of the globe, 29.82 inches in thickness. The specific gravity of water being considered as 1, that of mercury is represented by 13.568. A cubic inch of water at the temperature of 60° F. weighs 252.5 grains; hence, a cubic inch of mercury weighs 3425.92 grains, or 0.48956 lbs. avoirdupois ; and, multiplying this by the height, 29.82, we find that a column of air reaching from the surface of the earth to the highest point to which an elastic fluid can extend, with a base of one square inch, weighs about 14.6 lbs. avoirdupois, and exerts a pressure upon the earth and every thing on it to this amount. Air at 60° F. weighs 0.311446 grains to the cubic inch, and, were it of the same density throughout, it would be 328,021 inches high, or 27,335 feet, — about 5.17 miles.

The following facts will enable us to form some estimate of the weight of air and its pressure.

On one square inch it presses with a weight of				14.6 lbs.
On one square foot	"	"	"	2102.4 "
On one square yard	"	"	"	18,921.6 "
On one square mile	"	"		26,166,000 tons.
The weight of a cubic foot of air is				538.1 grs.
13.06 cubic feet of air weigh				1 lb.
29,260	"	"	"	1 ton.

1 lb. of air has a volume of 22,570 cubic inches.

That we are not aware of the immense pressure to which our bodies are exposed is owing to the fact, that the pressure is in all directions, nor only upon the ex-

terior, but upon the interior ; in all the cavities, and in the fluids themselves. When the pressure is increased so suddenly that the equilibrium is not restored, it is rendered cognizable to our senses ; this occurs in descending beneath the surface of the water in a diving-bell, the air within which sustains not only the usual pressure, but the additional weight of the water above it. Temporary deafness is almost always felt from this cause ; the pressure being communicated immediately through the external opening of the ear upon the drum, but finding its way more slowly through the mouth and narrow tube which communicates with the inner surface of this membrane. This inconvenience can, however, be readily removed, by increasing the internal pressure ; by closing the nostrils and mouth, and attempting to blow forcibly ; the air enters the cavity, and the equilibrium is restored.

Air gains admission to the fluids, not by any direct passage as in the instance just mentioned, but by means of a property it possesses of permeating the walls of the containing vessels or cavities ; the same property, indeed, by which the interchange between the different gases is effected in the lungs, as will be more fully explained in the chapter on Respiration. After it has once come in contact with the blood and other fluids the additional pressure will produce an absorption by them of the amount of air required to restore the equilibrium.

The air, as we have before stated in the remarks on gases, is a perfectly elastic fluid, its elasticity varying

inversely with the distance of the particles from each other. The weight obviously diminishes as the height increases; and it is easy to show, that, if the altitudes above the surface of the earth be taken in an arithmetical progression, the density of the air at these altitudes will diminish in a geometrical progression. According to this rule the following table has been formed, showing the relative densities at different heights.

Table of the Density of the Air at various Heights.

Height.	Density.
1 mile	1.
2 "	0.7943
3 "	0.6309
4 "	0.5011
5 "	0.3981
6 "	0.3163
7 "	0.2511
8 "	0.1995
9 "	0.1585
10 "	0.1260

From this table we see that air at the height of 10 miles has a density only one eighth that at the surface of the earth. The actual height of the atmosphere is still a matter of doubt among philosophers, but there are many reasons which tend to show that it is of finite extent. Refraction is the bending of light in passing through mediums of different densities, the refraction being greater as the medium is more dense; astronomers, from observations made upon this phenomenon, and upon the twilight, which depends upon it, have been led to believe that the height of the atmosphere does not much exceed 45

miles. That it does not extend through space is certain, from the fact, that it has not collected about the sun, or about Jupiter, which their size would certainly compel it to do by the laws of gravitation.

Heat of the Atmosphere. — Atmospheric air allows the sun's rays to traverse it in all directions without its temperature being in the slightest degree elevated. All the changes of temperature are occasioned by its contact with the surface of the earth and other solid bodies; it is greatest, during sunshine, in contact with these bodies, and diminishes as we ascend, nearly in the proportion of 1° F. for every 100 yards in height in summer, and a little less in winter. This rule is true for 7,000 or 8,000 yards at least, within which limits confirmation is derived from direct experiment in balloons, and from the velocity of sound. At the equator, the limit of perpetual snow rises to the height of 15,000 feet above the level of the sea, and descends as we approach the poles, where it is coincident with the surface of the earth.*

Although the heat as indicated by the thermometer, the *sensible* heat as it is called, is so much less in the upper

---

* Prout, Bridgewater Treatise, p. 106, gives —58° as the limit of cold on the surface of the earth.

The range of the temperature of the air is about 180°. In some of the expeditions to the North Pole, the thermometer has indicated —50°; Captain Parry, at Melville Island, noted —55°. At Benares, it has been noted as high as 110°, 113°, and even 118°.

In this latitude (42° 21′ 23″) June 10th, at 1 P. M., a thermometer laid in the sun, upon a nonconducting substance, a buffalo-robe, and protected from the air, indicated 165°.

regions of the atmosphere than at the surface of the earth, we must not infer that an equal weight of air actually contains less heat; it in fact contains precisely the same in the one place as in the other. If a pound of this thin and attenuated air were brought down, or in any way compressed to the density of the lower and heavier, it would raise the thermometer to the same point; the heat would, as it were, be forced out of it. Air does not feel cold because it has descended from a higher region, but because it has passed rapidly from a more northerly to a more southerly position.

Diffusion of heat is influenced by the law of the diffusion of gases; the same gas, under different temperatures, and consequently with different specific gravities, has the same diffusive tendency as different gases with varying specific gravities, the diffusion depending solely upon this difference. The propagation of heat is also dependent upon air in motion, or winds.

In a clear night the earth is cooled down by radiation, and the layer of air in contact with its surface becomes also cooler than that above it; it is to this cause that we owe the deposition of dew, as will be explained more fully.

Movement of the Air, or Winds. — Changes of density in the atmosphere produce an immediate motion of the heavier portions towards the lighter. Although other forces may have a limited influence, alterations of temperature are the great and efficient causes of this disturbance of equilibrium; the solar heat warms the earth, which, in its turn, communicates heat to the air, and an

upward current is immediately established. The alternation of day and night, and the revolution of the seasons, cause winds of a greater or less duration and extent. The ocean and the large inland seas or lakes are great and constant causes of motion in the atmosphere. The temperature of their surface varies but little during a considerable length of time, while that of the earth undergoes frequent fluctuations. Were the whole surface of the globe covered with water, the motions of the atmosphere must, from the very absence of these fluctuations, have been of very limited extent ; the almost daily east wind of spring, so well known to invalids on the New England coast, and the sea and land breezes, so remarkable for their regularity in tropical climates, owe their existence to this fluctuation. Were it not for these last, large tracts of country, in hot and arid regions, would be rendered altogether uninhabitable ; but their winds, cooled as they are by contact with the ocean, and supplied with moisture, return, bringing with them those invigorating qualities which impart to the fainting animal and withering vegetable, power to resist the influence of a scorching sun.

The explanation of these winds is obvious. During the day, the surface of the land, becoming heated, warms by its contact the air above it ; the air, having thus become specifically lighter, is pressed upward by the colder and heavier air from the sea, which rushes in to restore the equilibrium. During the night, the earth, parting with its heat, cools, and the sea being

now the warmer surface, an upward current is formed over that, and an equalizing current from the land arises.

The velocity of these winds may be made the subject of calculation ; it must be that with which air would escape from an aperture under a pressure equal to the difference of weight of the warm and cold columns. If the air, in a chimney 30 feet in height, be heated 80° F., it will be expanded as 1 to $1 + \frac{80}{491}$ or $\frac{1}{6} = 5$ feet, and will be driven upwards, according to the laws of spouting fluids, with a velocity equal to $8\sqrt{5} = 17.88$ feet per second. If the air over the land be 5° warmer than that over the sea, the difference in length of these columns of air if the atmosphere be 2,500 feet high, will be 25.5 feet, and the velocity acquired by the inrushing sea-breeze would be $8\sqrt{25.5}, = 40$ feet per second, or rather more than 27 miles per hour ; meeting, however, with many impediments to its motion on the earth's surface, it would be greatly diminished.*

The *trade winds* arise, for the most part, from the difference of temperature between the torrid and frigid zones. The mean temperature of the atmosphere near the equator, at the level of the sea, is 80° ; that of the polar regions is below 32°. In consequence of these constant differences, the air at the equator rises and spreads out in the upper regions, on each side, towards the poles, from which the colder air flows in to supply its place. If the earth were not in motion, the inflowing

---

* Encyclopædia Britan., Art. Meteorology.

currents would be due north on the north side of the equator, and due south on the opposite side, over its whole surface ; but the motion of the earth from west to east, which increases from the poles to the equator, where it is about 1,000 miles per hour, gives to the northern and southern currents an apparent motion from the east. Near the tropics, these winds are nearly due east ; but as they advance towards the equator they acquire more and more the velocity of the earth, — although that also is increasing, but more slowly,— and gradually change their easterly course, until at last, they resume their original northerly and southerly direction and again move upward.

The irregular currents in the air are determined by a great variety of causes. The atmosphere next the earth, from its lightness, must be in a state of unstable equilibrium, and the slightest causes, as inequality in the surface of the country, or in the character of the soil, as respects its heat-absorbing power, may determine an up-moving current.

Count Rumford, in his Essays, Vol. II., p. 377, describes an instrument, which he contrived, to show the movements of fluids produced by heat. It was a flat box, formed of two panes of glass, about one foot square, set in a frame parallel to each other, and one inch a part. In the upper side of the frame was an opening for filling the space with fluid, and another at the bottom for withdrawing it, each fitted with a cork, and the whole instrument made water-tight. Having half filled it with a solution of a vegetable alkali (a solution of carbonate of potash

probably), he mixed with it a quantity of pulverized amber, care being taken to make the strength of the solution such that its specific gravity should be equal to that of the amber. The instrument was then set in a window. The difference of temperature between the external air and that of the room soon produced motions in the liquid. Rumford's feelings while watching these motions may be gathered from the following paragraphs.

" How great was my surprise, when, instead of the vertical currents I expected, I discovered horizontal currents, running in opposite directions, — one above another, — or regular *winds*, which, springing up in the different regions of this artificial atmosphere, prevailed for a long time with the utmost regularity; while the small particles of the amber, collecting themselves together, formed clouds of the most fantastic forms, which, being carried by the winds, rendered the scene perfectly fascinating!

" It would be impossible to describe the avidity with which I gazed on these enchanting appearances.

" Nothing seemed wanting to complete this bewitching scene, and give it the air of perfect enchantment, but that lightning, in miniature, should burst from these little clouds; and they were frequently so thickened up, and had so much the appearance of preparing for a storm, that, had that event actually taken place, it would hardly have increased my wonder and ecstasy."

Moisture. — Atmospheric air always contains more or less aqueous vapor, either in an invisible state, or in the

form of clouds, fogs, and mist. The form of vapor most commonly known is that of steam, which is vapor at the temperature of 212°, having an elasticity equal to that of the atmosphere, or thirty inches of mercury; this, however, is not the form with which we are now most interested. Vapor exists in the atmosphere at all temperatures, even below the freezing point of water. Its elasticity at 32° is equal to supporting only $\frac{2}{10}$ of an inch of mercury. When the temperature of air cannot be diminished without depositing water upon the walls of the containing vessel, or appearing as a mist, it is said to be saturated. If the temperature of saturated air be raised, it will, to the feelings, become drier, and will immediately begin to take up water which is exposed to it; air is dry or moist, not in proportion to the water it contains, but in proportion as it is more or less removed from the point of saturation.

The point of saturation rises more rapidly than the temperature. A quantity of air absolutely humid at 32° F. holds in solution an amount of vapor equal to $\frac{1}{160}$ part of its weight; at 59°, $\frac{1}{80}$; at 86°, $\frac{1}{40}$; at 113°, $\frac{1}{20}$; and at 140°, $\frac{1}{10}$. Consequently, while the temperature advances in arithmetical progression, the dissolving power of the air rises with the accelerating rapidity of a geometrical series having a ratio of two.*

The influence of this law is evident in the production of rain and clouds. When masses of air of different

* See Table of Quantities of Vapor dissolved in Atmospheric Air at different Temperatures, Appendix, No. V.

temperatures, each containing its full amount of aqueous vapor, mix, the result must be a deposition of moisture in one or the other of the two forms just mentioned. Suppose, for instance, the two masses of air be at 55° and 75°, the resulting temperature will be an arithmetical mean, or 65°; the force of vapor at 55° is 0.4327 ; at 75°, 0.8581 ; and that at 65°, 0.6146 ; the mean force is not 0.6146, but 0.6459, which corresponds to a temperature higher than 65°; consequently a deposition of moisture must take place.

It is from this cause that steam appears as a cloud when escaping from the safety-valve of a steam-engine, or the nose of a tea-kettle ; the pressure of steam at 212° is greater than that which belongs to steam at the temperature of the air, consequently the excess of vapor is deposited.

After continued cold weather, when our houses have been throughout reduced in temperature, and a warm moist wind succeeds, we perceive that moisture collects upon the walls and furniture, or any other cold object ; the cause of this deposit is to be found in the fact, that the air in immediate contact with these objects is lowered in its temperature, and, being already nearly saturated, all the vapor above that due to this lower temperature immediately appears in the form of minute drops. A glass tumbler, filled with cold water, in summer, is soon bedewed with moisture, not, as is frequently imagined, because the water oozes through the tumbler, but because the air around it is cooled, and its moisture precipitated upon

it ; the same would occur in winter, if the tumbler were brought into a close room, in which many persons were assembled, and the air loaded with the accumulated vapor exhaled from their lungs and skins. From the same cause, the cold windows of a crowded lecture-room, in winter, not provided with efficient ventilation, are constantly covered with minute drops of water, which soon collect together and run down the glass in streams.

The highest point of the thermometer at which vapor begins to be deposited by the air is called the *dew-point* ; it is the point at which dew begins to form. When the direct influence of the sunlight is removed, all bodies exposed to the clear sky begin to throw off the heat they have received ; that part which is thrown off into space does not return, and the temperature of the body begins to fall ; when this temperature, as in the other cases we have mentioned, is communicated to the surrounding air, and cools it below the point of saturation, it gives up a portion of its vapor in the form of dew. That dew forms upon some bodies in greater quantities than others is owing to their superior radiating power, or power of throwing off heat. Thus, green grass has more radiating power than pine-boards, and these last than a gravel walk ; consequently dew will be deposited upon the first in larger quantity than the second, and on the second, than the third. A calm night must obviously conduce to the formation of dew, since it allows the air to remain long in contact with the cooling bodies ; while winds continually bring new portions of air, each of which is but

slightly reduced in temperature. A cloud, or an overhanging tree, radiates to the grass the heat it has received, and thus prevents a sufficient reduction of temperature to produce dew. *Frost* is but frozen dew, and merely indicates a greater degree of cold.

The clouds, which are formed by the precipitation of the vapor of the air, are not composed of drops of rain, although when descending to the earth they assume that form, but of minute vesicles or bladders, containing vapor, and perhaps a gas. M. De Saussure, while travelling upon the Alps, encountered a large cloud, composed entirely of these vesicles, which were seen to float slowly by him, some of them larger than the largest peas.

The steam arising from the surface of a heated liquid has this form. If the liquid be of a dark color, — a cup of coffee, for instance, — and is placed in the sunlight, this vapor may be seen floating like a cloud upon its surface, or rising a little above it; if examined with a magnifying-glass, warmed, that it may not be obscured by condensation, the cloud will be seen to be composed of distinct vesicles, appearing to roll here and there upon its surface, like small shot; the appearance is so peculiar, that it well pays one for the trouble of making the experiment.

Some of the London fogs, which are vesicular, have been made to disappear by heating them to 80°; from which it was inferred that the vapor was about $\frac{1}{70}$ of the weight of the air which contained it. This constitution of

clouds explains, in some manner, their floating in the atmosphere ; were they formed of drops even of $\frac{1}{1000}$ of an inch in diameter, they would acquire a constant velocity in falling of nine or ten feet per second ; while under the vesicular form they are readily conveyed from one point to another by the constantly changing strata of air.

Although evaporation is going on at all temperatures, it increases rapidly with an increase of temperature ; it is also influenced by other circumstances. Mr. Dalton found by experiment, that in *dry* air the rate of evaporation was always in proportion to the elasticity of the vapor generated, measured by a column of mercury. As the atmosphere always contains some vapor, this rate of evaporation does not hold good ; if the air is saturated, no evaporation takes place, and it is increased as the quantity of water in solution diminishes. To ascertain the rate of evaporation, we must first ascertain the elasticity of the existing vapor, and subtract it from that due to the temperature. Suppose the temperature to be 65°, the force of vapor at that temperature is 0.61 of an inch of mercury ; if the amount of vapor already existing be 0.31, and this be subtracted from the first quantity, we shall have a difference of 0.30, which corresponds to a temperature of 46°.* Hence we see that in moist air, at the temperature of 65°, evaporation will go on no faster than in dry air at 46°.

Mr. Howard ascertained that a circular area of snow,

* See Dalton's Table of Force of Vapor from 32° to 80°, Appendix, No. VI.

five inches in diameter, lost by evaporation 150 grains between sunset and sunrise, and 50 grains more before night. In this experiment, the snow was exposed to a smart breeze upon a house-top ; an acre of snow exposed to a similar breeze would lose in the same time 64,000,000 grains, or 11,111 pounds of moisture. During the night only, about one thousand gallons of water would be raised from an acre of snow.

The evaporating power of air raised from a low to a high temperature is greatly increased. We notice this most frequently in the dryness and consequent shrinking of our furniture, door-panels, and other wood-work of our houses, when warmed by heated air to which a sufficient quantity of water has not been added.

If the force of the vapor in air at 32° be 0.20 of an inch of mercury, and that in air at 68° be 0.68, we have a difference of 0.48, which corresponds to 58°, and the rate of evaporation will be $2\frac{1}{2}$ times greater at this last temperature than at 32° ; to supply this demand for moisture, all articles containing it will be compelled to yield their due proportion.

We have before stated that vapor permeates the bulk of the air, as does a gas ; it results from this, that two equal volumes of the vapor and air, when mixed, do not form a mass equal to the sum of the two, but one which is due to the sum of the elastic forces. If air at 32°, with an elastic force of 30 inches of mercury, be mixed with an equal volume of vapor at 32°, the elastic force of which is 0.2 of an inch, the volume will be in-

creased by this amount, or $\frac{1}{150}$. Hence we see that the specific gravity of the air is but slightly diminished by the addition of vapor ; but in proportion as the temperature is raised, the elastic force increases and the resulting volume is increased. At 212°, steam is but $\frac{5}{8}$ the weight of air ; but, as its elastic force is equal to that of the air, the volume will be doubled by the mixture, and the resulting specific gravity will be much less than that of the air ; this occurs also at the temperature of the body, 98°, and is one of the causes of the ascension of the air expired from the lungs.

Attention to this fact is of great practical importance in the construction of drying-rooms and laundries. If the opening for the escape of the heated air be at the bottom, as it becomes saturated with vapor it becomes lighter, and will remain at the top, effectually preventing all evaporation. If the opening be at the top, on the contrary, the air in rising becomes more and more moist, and escapes loaded. The drying in these cases always commences at the bottom.

In the transition of a fluid to the state of vapor, much heat is taken up or rendered latent, and the liquid giving off the vapor falls in temperature.* Under the receiver of an air-pump, if the pressure of the air be removed from a saucer filled with water, evaporation goes on rapidly until the receiver becomes filled with

* Water, in assuming the form of steam at a temperature of 212°, absorbs or renders latent about 1,000° of heat ; that is, a gill of water converted into steam at 212°, would, on being condensed in 1,000 gills of water at 60°, raise it one degree.

vapor, when it ceases ; but if this vapor, which cannot be pumped out, be removed by sulphuric acid, which has a great affinity for it, the evaporation will be constant, and the water will freeze. Evaporation is a cooling process. In condensing a vapor into a fluid, a large quantity of heat is given out, and it becomes a heating process. If our bodies, then, be exposed to a very warm and dry air, we shall feel cool, or even cold, from the rapid evaporation from our skins ; a certain amount of moisture, then, acts as a saving of heat. We see, also, why, in a warm, damp day, we suffer more from heat than in a dry one ; the cooling process does not go on, and the perspiration accumulates upon the surface.

The moisture on the skin when the body is thickly and closely covered in bed is not necessarily due to increased perspiration, but to the saturation of the air, by which it is prevented from carrying away the usual amount of perspiration. A more free, but less obvious, perspiration would be produced by a free circulation of air through light clothing ; and an increased amount of heat, by means of bottles of hot water or heated stones placed around the body.

It is important that we should possess some means of estimating the quantity of vapor in the atmosphere, if we would give to the air of our houses a proper amount of this important constituent. Several ways have been devised, one of which is to pour into a thin glass tumbler water sufficiently cold to produce a deposition of moisture upon the outside, and, stirring it with a ther-

mometer, note the degree at which it disappears ; this is the dew-point, or point of saturation. But this is a tedious process, frequently requiring ice and no inconsiderable amount of patience. A shorter and more convenient way is founded upon the degree of cold produced by evaporation, for this must depend upon the rate of evaporation, which again depends upon the amount of moisture in the air. Two thermometers whose scales agree are selected, and the bulb of one covered with cotton cloth and wetted with water ; they are both swung in the air until the mercurial columns become stationary, and their heights noted. The number corresponding to the difference of these heights in the table given in the Appendix, No. VII., which may be found according to the directions there laid down, is the dew-point. This is sufficiently accurate for ordinary purposes of ventilation.

Electricity. — There is reason to believe that the passage of masses of air by, and rubbing against, each other, of different temperatures, or containing different degrees of moisture, developes electricity. It is well known, that, when high-pressure steam is allowed to escape from a jet, the vapor is highly positive, and the jet with the attached boiler negative. Dry steam or steam of very high pressure produces no electricity ; it is necessary that the steam should be partially condensed before it reaches the outlet ; hence, we may consider the steam as acting as a moving force, while the watery particles are rubbed against the sides of the jet. A locomotive

engine, which was insulated by being raised on blocks of dry wood, was found to be in a state to receive sparks from bodies about it connected with the earth. It has been supposed that the watery particles with which the air is charged may become positively electric by being driven and rubbed against the earth, its rocks and trees.

Evaporation produces electricity when taking place slowly and without any aid from friction. If a saucer be insulated by being suspended with silk cords, the evaporation goes on as usual at first, and then greatly diminishes in its rate, and so remains while it remains insulated; on putting the saucer in communication with the earth by a chain or any other conductor, evaporation resumes its usual rate. In this case, as in that just mentioned, the vapor is positively electric and the saucer negatively. Evaporation is thus going on over the whole surface of the earth, the vapors transmitting to the air positive electricity, while the earth preserves negative electricity.

Combustion produces electricity, the carbonic acid which escapes becoming positively electrified, while the burning body remains in a negative state. Respiration also affords an additional amount of positive electricity to the atmosphere; and probably the gaseous fluids given out by plants during the process of vegetation do the same.

At sunrise the atmospheric electricity is feeble, but increases during the forenoon, as the vapors collect in

the lower regions of the atmosphere. About noon the tension attains its *maximum*, when the air contains the greatest amount of vapor. Immediately after reaching the *maximum*, the electricity diminishes at first rapidly, and then more slowly; as this proceeds, the visible vapor disappears and the atmosphere becomes clear. At two o'clock in the afternoon the atmospheric electricity is scarcely stronger than at sunrise; it continues to diminish till two hours before sunset, about which time it begins to advance, and attains a second maximum an hour and a half or two hours after sunset. During this time, vapors have formed low in the air, and the night-dew has fallen. After continuing in this state for a short time, the electricity diminishes gradually till morning. During the whole course of these diurnal changes, we see a manifest connection, in time at least, between the pressure of vapor and the development of electricity.

That there is a connection between the electric state of the atmosphere and our feelings we cannot doubt. In general, when the air is clear, and electricity is developed with great rapidity, there is a buoyancy and good spirits which do not exist in an opposite state. Attempts have been made of late, by a continued series of observations, to trace a connection between prevalent diseases and the electrical state of the atmosphere, but as yet no great progress has been made.

CHAPTER IV.

Respiration. — Its Objects are the Removal of Carbonic Acid and the Introduction of Oxygen. — Lungs, anatomical Structure. — Number of Respirations. — Capacity of Lungs. — Amount of Carbonic Acid generated. — Varies with Hour of Day and other Circumstances. — Of Endosmose and Exosmose. — Changes which the Blood undergoes in the Lungs. — Aqueous Vapor expired. —Varies with Amount of Vapor already existing in Atmosphere. — Absorption by Lungs. — Skin secretes Moisture. — Its Quantity. — Analysis of Air contaminated by Respiration.

The function of respiration consists in an interchange of the ingredients of the blood and the medium to which it is exposed. The blood, in its passage through the capillaries, parts with some of its elements and absorbs others, the removal of which from the system is essential to its existence in a living state. If carbonic acid, for instance, were retained, the blood would stagnate in the capillaries, one of the most important of the forces which propel it would be destroyed, and death soon ensue. That a certain degree of heat is required for the circulation cannot be doubted, and that the elimination of carbon and its combination with oxygen would produce this heat is equally true ; but there are probably other objects to be attained, the precise nature of which are as yet unknown. Although this substance be removed, without the introduction of an oxygenated gas into the lungs, yet death will take place at last from the

want of oxygen. In proportion as the animal is more active, this gas becomes more necessary to the organism, to a degree almost equal to that of the removal of carbon. To the animal kingdom it is a stimulant as essential to the performance of the various functions, as heat and light to both kingdoms.

The constant provision manifested for the aeration of the circulating fluid sufficiently attests its importance ; with the exception of nutrition and the reproduction of the species, no function is so universal.

The human lungs are two in number, situated one on either side of the heart, which they nearly conceal. They are of a conical form, the apex rising above the level of the first rib, enlarging as they descend, and resting upon the diaphragm. Each lung is covered, and the ribs are lined, by a smooth, moist membrane, which facilitates the motion of these organs. The windpipe is connected with a system of tubes by which air is conveyed to all those parts of the lungs in which respiration takes place. These tubes, by many successive divisions, become extremely small, and finally terminate in a minute cell or air-vesicle. These vesicles do not communicate with each other ; their only opening is that of the minute tube which leads to them. To each of these cells belong a small artery and vein which form around it a capillary network, so close that the diameter of the meshes is scarcely so great as that of the vessels which form them. It is in the vesicle that the interchange between the blood and air takes place. The dark-colored ve-

nous blood arrives through the pulmonary artery upon the immense surface which all these cells offer ; it is exposed to the action of the contained air,* changes to a bright arterial tint, and returns by the vein to the left side of the heart, thence to be sent on its circuit through the system.

By means of the alternate action of the diaphragm and abdominal muscles the air is alternately drawn into and forced out of the pulmonary air-vesicles. It is difficult to ascertain the precise number of these alternate contractions and dilatations, since, when the attention is directed to them in our own persons, they increase in frequency and amount. From a number of experiments, it is probable that the average is between fourteen and eighteen † each minute ; of these, the ordinary inspirations involve but little movement of the chest, but an increased exertion takes place every fifth recurrence. In a healthy state, the respiratory movements are to the pulsations of the heart as 1 to 4½ or 5 ; in some affections of the lungs, and in some states of the nervous system, great deviation from this rule occurs.

Great difference of opinion exists among experimenters as to the capacity of the lungs, and the amount

---

* The physical laws, in accordance with which this interchange takes place, are those of *endosmose* and *exosmose*. They will be again referred to more particularly.

† Dumas estimates his own respirations at sixteen per minute ; Mr. Coathupe, whose experiments were made on 266.66 cubic feet of air, also considers the average to be sixteen. Reports of the British Association, 1839. Dr. Thompson also rates the average at sixteen. Liebig and some others consider eighteen per minute as the average.

of air taken in at each inspiration. These discrepancies arise from two causes, the inability of attending to one's own respirations without influencing them, as just mentioned, and the difficulty of inhaling air from an apparatus with the same regularity and amount as in natural breathing. From experiments by Dumas and Mr. C. F. Coathupe, the amount of air used by the latter gentleman being 266.66 cubic feet, it appears that twenty cubic inches is a near approximation to the amount of air inspired at each dilatation of the chest.*

The earliest accurate experiments on respiration are those of Lavoisier and Seguin. They found that the air expired contained more carbonic acid and less oxygen than that inspired ; the amount of carbonic acid being somewhat less than the oxygen which had disappeared. It was supposed by them that the oxygen had united immediately with the carbon of the venous blood in its passage through the lungs, forming the carbonic acid expired. Subsequent researches have shown that this is not a true account of the changes which take place in the lungs. Recent investigations in organic chemistry lead us to believe that oxygen combines with the red

* Assuming the above estimates to be correct, we have passed through the lungs of each individual the following quantities of air in the time set against them.

One inspiration . .	20 cubic inches.
One minute . . .	11 pints.
One hour . . .	11 cubic feet.
One day . . .	266 cubic feet.
One year . .	97,090 cubic feet,

which is equal to a cube 46 feet by the side.

particles of the blood, and is carried by them to the various parts of the system ; that in the capillaries it unites with the carbon of the different organs, forms carbonic acid, which is again conveyed by the globules of the venous blood to the lungs, and passing into the air by exosmose, a corresponding portion of oxygen is absorbed.

The quantity of oxygen which disappears from the air and is not accounted for in the carbonic acid varies considerably ; it is sometimes as much as one third of the whole ; it is greatest in the young animal, and sometimes almost imperceptible in the adult.

Amount of Carbonic Acid generated. — The quantity of carbonic acid excreted has been estimated at 39,534 cubic inches in twenty-four hours ; this is equivalent to 11 ounces troy of pure carbon. To this it has been objected, that it is more than is contained in six pounds of most kinds of solid food used by man ; for this usually contains three parts in four of water, and of the other part seldom more than one half is carbon.* Hence, making no allowance for what passes off in other ways, more carbon is excreted from the lungs, according to this estimate, than is introduced in the daily amount of food. According to other experiments, in which much confidence can be placed, it is estimated at 18,420 cubic inches, or about five ounces of carbon in twenty-four hours. From these last mentioned experiments it appears that the amount of carbonic acid in the expired

* Müller's Physiology, Vol. I., p. 308.

air is four per cent. of the whole. Allen and Pepys found it, in their experiments, as high as 8.5 in a hundred parts. They found also, that, when the air to be respired contained carbonic acid, the amount excreted was less; 300 cubic inches of air respired three minutes gave only twenty-eight and a half cubic inches of carbonic acid, while, when fresh air was taken in at each inspiration, the amount excreted was thirty-two inches per minute. We cannot fail to infer from this fact, knowing as we do the necessity of the free excretion of carbonic acid, the great importance of ventilation, since the more frequently any quantity of confined air is breathed the more it will interfere with the due aeration of the blood.

Dr. Prout's experiments show that the quantity of carbonic acid generated in a given time is greatest between the hours of eleven, A. M., and one, P. M.; smallest between eight, P. M., and three, A. M. It is also greater when the barometer is low.* During a state of muscular activity it is greatly increased, as we must have inferred from the fact that it is derived from the oxidized products of the system, no motion in which can take place without a union of its parts with oxygen. Mr. Newport has noticed that this difference is enormous in insects. When at rest, their respiration is as feeble as that of cold-blooded animals; and when in active

* Dumas, Essai de Statique Chimique des Ètres organisés, p. 82, examines the question of the quantity of carbon with much care, and concludes, all things considered, that the production of 154 grains troy per hour is a near approximation for the common mass of men.

5*

movement, they consume more oxygen, in proportion to their size, than any animal. In man the difference is not so great, but it is unquestionable that when in motion an increase does take place. The secretion of carbonic acid is diminished during sleep, probably on account of the cessation of muscular exertion and the warmth of the body; for it is ascertained that more is secreted at a low than a high temperature.

It has been mentioned that the oxygen consumed is not all accounted for in the carbonic acid formed. A series of experiments has been instituted by Dulong to ascertain the amount lost. He placed animals in an apparatus from which the air could be constantly removed, and new air supplied. On testing it, he found that during the respiration of all animals more oxygen was consumed than was replaced in the carbonic acid formed. The quantity thus lost amounted on an average, in the herbivora, to $\frac{1}{11}$ of that replaced by the carbonic acid; in the carnivora it amounts to $\frac{1}{5}$ or $\frac{1}{2}$. Despretz's experiments gave the amount of the same gas lost as $\frac{1}{3}$ or $\frac{1}{4}$.

The reaction which takes place between the air and blood is explained according to the physical laws of *endosmose* and *exosmose*, or, in other words, the laws of "inflowing" and "outflowing."* Gases and thin fluids, together with the matter they hold in solution, permeate moist animal textures.† If two kinds of gases be placed

---

* Daniell's Introduction to Chemical Philosophy, p. 63. Müller's Physiology, Vol. I., p. 259. Carpenter's Compar. Physiology, p. 336.

† John Hunter, in 1755, ascertained this fact. Treatise on the Blood, p 44.

in contact with a moist animal membrane, a bladder, for instance, the one being inclosed and the other external to it, each permeates the bladder until they are equally mixed. This process takes place even when the bladder has been dried and again moistened. A gas will permeate a moist bladder, and be absorbed by a fluid contained in it. It is in this way that gaseous matters permeate the membranes of the lungs, and are dissolved in the blood circulating in the vessels distributed on the walls of the vesicles. If a piece of moist bladder be tied over a tumbler completely filled with water, and salt be strewn upon the bladder, it is dissolved, and finds its way into the water contained in the tumbler. A salt in solution has a tendency to diffuse itself through every other fluid with which it is miscible. Further, it is found that a fluid charged with any gas it will absorb (as water with carbonic acid) will speedily part with it when exposed to the attracting influence of another gas, such as atmospheric air; the greater the difference in the density of the two gases, the more rapidly and the more forcibly will this take place.* At the same time that the fluid parts with one gas, it absorbs the other in its place. A porous membrane offers no more interruption to the process than the tube uniting the two vessels, mentioned in the observations on the diffusion of gases. In these facts we find the key to the explanation of the changes taking place between the blood and surrounding air. The carbonic acid of

* It is owing to this cause that the agitation of a glass of champagne wine, after it has become still, reproduces effervescence.

the former is exhaled, and the oxygen of the latter absorbed.

Changes which the Blood undergoes in the Lungs. — Since the discovery of the circulation of the blood, it has been known that an important change is effected in the character of the blood by exposure to atmospheric air in the lungs. The most striking change is in the color, from the dark purple of the venous fluid to the rich crimson of the arterial. But it is the changes in the chemical character of the blood, of which this color is the index, with which we are interested. By careful and accurate experiments on the blood, it has been ascertained that both arterial and venous contain carbonic acid, nitrogen, and oxygen, but in different proportions; venous blood contains most carbonic acid, and arterial blood most oxygen; the proportion of nitrogen in the two is not always different. The quantity of gas contained in the blood amounts in the mean to $\frac{1}{10}$ of the volume of the blood itself; the oxygen of the venous blood equals at most $\frac{1}{4}$, and often only $\frac{1}{5}$, of the carbonic acid which the same blood contains; while in the arterial blood the oxygen equals at least $\frac{1}{3}$, and almost always $\frac{1}{2}$, the quantity of carbonic acid. These gases, it must be remembered, do not exist in the blood in an aeriform state, but are in a state of solution in it, just as atmospheric air is in the water of rivers.

The globules of blood contain a compound of iron; it is always present.* From a consideration of the char-

* It is said that the wife of a distinguished French chemist wears a ring made of the iron of the blood drawn from her husband during an

acters of the compounds of iron, it has been supposed that the iron of the blood is saturated with oxygen, and that it loses a part of it in the living state during its passage through the capillaries, the oxygen uniting with the organic matter of the system. One of the products of oxidation formed in the process is carbonic acid. The compound of iron in the venous blood has the property of combining with carbonic acid ; hence the globules, if they lose a part of their oxygen, will, if they meet with carbonic acid, combine with it. When the globules reach the lungs, they will again take up the oxygen they have lost ; for every volume of oxygen absorbed they will yield a corresponding volume of carbonic acid, will return to their former state, and may again give off oxygen. As carbonic acid contains its own volume of oxygen without condensation, for every volume of oxygen which the globules give off there will be formed an equal volume of carbonic acid.* According to these views, the globules of arterial blood in their passage through the capillaries yield oxygen to the constituents of the various tissues by which they become lifeless compounds. But a small portion of the oxygen would be required in this process ; the greater part is employed in converting into oxidized compounds these lifeless parts. In their return towards the heart, the globules which

---

acute disease. If, as is estimated, 10,000 parts of blood contain eight parts of peroxide of iron, four pounds of blood might give eight grains of metallic iron, sufficient for making a wire ring of the usual size.

* Liebig, Animal Chemistry. Respiration. Mulder supposes that the change of color in the blood is owing to a change of form in the globules.

have lost their oxygen combine with carbonic acid, producing venous blood ; and when they reach the lungs, an exchange takes place between this carbonic acid and the oxygen of the atmosphere. We see, then, that two processes of oxidation are going on ; one in the lungs, the other in the capillaries. By means of the former, in spite of the cooling from contact with the inspired air, and the evaporative process, the constant temperature of the lungs is kept up, while the heat of the rest of the body is supplied by the latter.

Besides the exhalation of carbonic acid, it is found that the expired air contains a considerable amount of aqueous vapor. The manner in which water is transferred from the blood is in accordance with the physical laws we have already mentioned. The amount of this vapor is variously estimated, according to the mode of conducting the experiment and the quantity already existing in the air. It is evident that exhalation can take place only when less vapor exists in the inspired than the expired air, and that it will take place just in proportion as this is less. The dew-point of the human breath has been ascertained to be 94°.*

* According to Dalton's table of the elastic force of vapor, it appears that a dew-point of 94° corresponds to a force of 1.53 inches of mercury; and as the specific gravity of vapor is but five eighths that of air, we find, by dividing the weight of air by the weight of the vapor $\frac{30 \text{ in.}}{\frac{5}{8}\,(1.53)}$, that the vapor is about one thirty-first part of the weight of the expired air. This is always more than is inspired; for the highest dew-point of the air is 80°, at which the vapor is one forty-seventh of the weight of the air. If we ascertain this last dew-point, and consequently the amount of vapor in the air, and subtract it from the quantity expired, the remainder must be that exhaled.

From calculations it has been estimated, that, with a dew-point of 32°, one pound of vapor escapes for every thirty-five pounds of expired air ; and with a dew-point of 75°, we exhale one pound for every sixty-nine. As the dew-point is higher in summer than in winter, we exhale less in the former than in the latter. The amount is usually estimated at sixteen or twenty ounces in the twenty-four hours. This is not pure water ; it contains carbonic acid gas and animal matter, and sometimes volatile substances which have been introduced into the blood, or formed in it. It is the animal matter which produces the putrid odor of this fluid when kept in a closed vessel. It is also noticed, that the breath of some individuals has a fetid odor, even when no carious teeth or ulcerations of the mucous membrane exist to occasion it. This is peculiarly obvious with many of the insane, often requiring distinct classification from this cause alone. In these cases it undoubtedly results from the excretion of odorous animal matter through the medium of the lungs.

Under some circumstances, absorption of vapors and gases takes place by the lungs. It is undoubtedly in this way that sulphuretted hydrogen produces its fatal effects, when mingled with atmospheric air ; it has been found that an atmosphere containing $\frac{1}{1500}$ part will kill a bird, and $\frac{1}{800}$ a dog. Professor Daniell has lately shown that the waters of some of the African rivers, whose mouths are remarkably unhealthy, are impregnated with this gas to a considerable degree, derived probably from animal and vegetable matter decaying in a hot climate.

Another gas which is more closely connected with our subject, inasmuch as it is one by which the inhabitants of all ill-ventilated apartments are constantly surrounded, carbonic acid, is also absorbed by the lungs. That this is the fact, and that the injurious effects are not solely attributable to the impediments offered to its exhalation, has been proved by experiment. It has been ascertained that a land tortoise may be deprived of the use of one lung by tying its air-tube, and yet support life by means of the other for some days ; but if one lung be made to inspire carbonic acid, while the other breathes pure air, instead of living days, the animal dies in a few hours.

We see, then, that the removal of the poisonous gases produced by respiration is doubly important ; for they act not merely by preventing the excretion of those which, if retained, will be injurious, but, after being excreted, they may be again introduced into the system.

The skin is also a secreting organ. That it secretes aqueous vapor is well known ; this is not exhaled by oozing through the pores physically, but is a vital process. The glands by which the secretion is produced are curiously contorted tubes, seated just below the true skin, and distributed over the whole surface of the body. The secretion finds its way to the surface by means of a spiral canal, opening obliquely, in such a manner that the thin external skin, or cuticle, acts as a valve upon its mouth. This secretion is usually in the form of vapor, which is dissipated as soon as formed, and is consequently insensible ; at other times it collects in minute

drops upon the skin, and becomes sensible, forming sweat.

The whole amount of fluid thus lost by the skin is supposed to be about nine grains troy per minute. Seguin estimated that lost by the two surfaces, cutaneous and pulmonary, at fourteen grains per minute ; five grains from the former, and nine grains from the latter. Supposing it constant, we should, according to these estimates, lose, at the maximum, two and a quarter pounds in twenty-four hours, and at the minimum, one pound and a half. This must be considered as an approximation only, since it must vary in some degree with the dew-point, and temperature, and the motion of the atmosphere. Temperature influences perspiration to a great degree, as is well known. It is the great protection against intense heat, — so great a protection, indeed, that the human body has been able to endure a heat more than one hundred degrees above its usual temperature, without itself experiencing any elevation. The secretion of the glands just mentioned increases rapidly with the temperature, stands upon and bathes the skin, and, while assuming the gaseous state, absorbs the free caloric which would otherwise heat the body. This will, however, take place only in a hot and dry atmosphere ; should it be already saturated, it will be no more supportable than a steam-bath of the same temperature. Hence, again, we see that the amount of ventilation must be increased with increased elevation of temperature.

Carbonic acid escapes from the skin also. In some

of the lower orders of animals, life can be maintained for many days by the respiration thus carried on. A living human limb has been inclosed in an impervious covering containing air deprived of carbonic acid, and yet, after a time, analysis did not fail to detect it.

We have now considered some of the changes which experiment has shown are produced by respiration in atmospheric air. They have been made principally upon few persons. Experiments confirming them have since been made upon a larger number, and under circumstances in which persons in assemblies, schoolrooms, and hospitals are usually found. The results will be found in the table in the Appendix, No. VIII., from the Memoir on the Analysis of Confined Air, by Felix Leblanc.

CHAPTER V.

Lighting. — Products of Combustion of Gas, Oil, Tallow, and Wax similar to those by Respiration. — Carbon essential to the Production of Light. — Consumption of Candles. — Quantity of Oil consumed by a common Lamp. — By an Argand Lamp. — Aqueous Vapor and Carbonic Acid given off. — Air required for Combustion of Oil. — Exclusive Lighting. — Faraday's Lamp, Glass, and Tube.

Lighting. — The products of the combustion of carburetted hydrogen gas, wax, oil, and tallow, which are used in the production of artificial light, are like those given out by respiration, carbonic acid and aqueous vapor. Wax, oil, and tallow are composed of carbon, oxygen, and hydrogen; the combination of oxygen with the carbon produces carbonic acid, and with the hydrogen, water; carburetted hydrogen is composed of carbon and hydrogen, which are also converted during combustion into water and carbonic acid. The oil, tallow, and wax are all converted into gases before combustion can take place with the production of light; but it is not the combustion of the vapor of carbon that produces the white light; that depends upon the precipitation of the solid portions of carbon; when burning as a gas, it affords a very feeble bluish light only.

Dr. Ure, before a committee of the British House of Commons, on lighting that house, in 1842, gave the following explanation with regard to flame. "In the burn-

ing of coal gas, and of all kinds of carburetted hydrogen, the white light is produced by ignition of the solid particles of carbon, precipitated first of all in the interior of the flame ; for the hydrogen burns first, from its greater affinity to oxygen ; and after it is partially burned, the carbon which was formerly combined with it, and as it were in a state of solution, is precipitated in solid particles ; and these solid particles, getting highly ignited, produce the white flame. Carbon, as long as it is in solution in the hydrogen, and if it be all burned simultaneously with that hydrogen, burns with a faint blue light. In the common Argand burner, the supply of atmospheric air being free, a portion of the carbon, near the base of the flame, for the space of about three quarters of an inch, is burned in its gaseous state, and gives out much heat with very little light." As the oil and tallow burn, after being first converted into gas, what is said of gas is true of these also.

From experiments made upon the burning of wax candles, it is found that what is called a short three-in-the-pound burns 125 grains of wax per hour. Wax contains 81.75 parts in 100 of carbon, and it can be easily shown that it generates by combustion 300 parts by weight of carbonic acid. Hence 125 grains of wax will generate 375 grains of carbonic acid, equivalent to 800 cubic inches of the gas.

From the mean of several experiments made with a two-wicked lamp, each tube being one fourth of an inch in diameter, the flame one inch and a half high, it was found

that two fluid drams of whale-oil were consumed each hour. Whale oil contains 68.8 parts in 100 of carbon, from which we conclude that two drams produce 254 grains of carbonic acid, or 540 cubic inches. An Argand lamp, burning brightly, consumed in one hour ten drams of oil, and would consequently produce 1270 grains, or 2700 cubic inches, of carbonic acid. The gas burner of the Boston Gas Company, with twenty-two holes and a chimney, with a flame about three inches long, burns four feet of gas per hour. A cubic foot of carburetted hydrogen, estimating its carbon at 75 parts in 100, produces 807 grains of carbonic acid, or 1720 cubic inches.

The aqueous vapor may be easily estimated, if we recollect that for every grain of hydrogen uniting with eight grains of oxygen nine grains of water are produced. The proportion of hydrogen in carburetted hydrogen is 25 parts in 100, or 73.5 grains in a cubic foot; see table, page 11; hence, 661.5 grains of water are evolved by the consumption of one cubic foot of gas.

The following facts will convey some idea of the amount of air consumed, and the impurities evolved, in the process of lighting.

A pint of oil when burned produces a pint and a quarter of water; a pound of gas, more than two and a half pounds of water.

An Argand gas-burner, in a shop-window, will produce in four hours two and a half pints of water, which

may be condensed upon the goods, the window, or any other cold substances.

The Argand burner of the Boston Gas Company with twenty-two holes will produce in four hours, when burning at the rate of four feet per hour, twenty-two ounces, or a pint and six ounces, of water, and four feet of carbonic acid, which will render *four hundred* cubic feet of atmospheric air unfit for respiration.

A pound of oil produces 2.86 pounds of carbonic acid, and consumes the oxygen contained in 13.26 cubic feet of atmospheric air.

A pound of coal-gas produces 2.56 pounds of carbonic acid, and consumes 4.25 cubic feet of oxygen, which is equivalent to that contained in 21.25 cubic feet of atmospheric air. For every cubic foot of gas burned, an equal quantity of carbonic acid is produced, and renders, according to Leblanc, 100 cubic feet of air unfit for respiration.

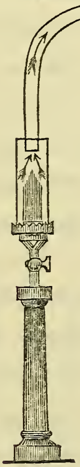
As an illustration of the demand for air to produce efficient lighting, we may mention the following. In the vestry of a meetinghouse in Boston, some years since, great complaint was made of the impurity of the oil used ; it burned well for a time, when the lamps grew dim, and continued to grow more so through the evening. The sexton was directed to procure better ; he tried many kinds, but all to no purpose. He had noticed, however, that, the longer he was compelled to remain after the services, and listen to the complaints of the aggrieved, the better his lamps burned, which was

soon interpreted to mean the improvement of the air consequent upon the opening of the doors and the departure of the audience.

To avoid the injurious effects which must follow from the impurities above mentioned, as well as to improve the quality of the light, *exclusive lighting*, as it is called, has been adopted. In this arrangement, the light is either entirely without the room to be lighted, the rays being admitted through glass, or tubes are provided, by which the products of combustion are conveyed by the chimney or other flues to the external air; in this case, the lamp is supplied with air from the room. In another mode, in which there is a tube for supplying pure air from without, the lamp is practically as exclusive as that first mentioned.

Professor Faraday adopted a very simple plan for

Fig. 1.



removing the products of lamps in a public room in

England. He placed a metallic tube about one inch in diameter over the lamp glass, dipping down into it one or two inches, and connecting by its other extremity with a flue, as is represented in fig. 1. The plan was perfectly successful.

To this succeeded a beautiful and apparently perfect form of lamp ventilation ; it is the application of a descending draught. The gas light has its glass chimney as usual, but the glass holder is so constructed as to sustain not merely the chimney, but an outer cylinder of glass larger and taller than the first ; the glass holder has an aperture in it connected by a mouthpiece with a metallic tube which serves as a ventilating flue, and which, after passing horizontally to the centre of the chandelier, then ascends to produce a draught and carry off the burned air.

Fig. 2, *a* is the burner ; *b*, the gas-pipe leading to the burner ; *c*, the glass chimney standing upon the glass-holder, which has an aperture in it opening into the mouthpiece, *d*, which is attached to the metal chimney, *i* ; *f*, *f*, an outer cylinder of glass closed at the top by a plate of mica, *g*, or, still better, by two plates of mica, one resting on the top of the glass, and the other, *h*, dropping a short way into it. They are connected together by a metal screw and nut, which also keeps them a little apart, thus forming a stopper, which cannot be shaken off the glass chimney, but is easily lifted on and off by the small metal ring or knob at top ; *k*, *k*, is a ground globe which may be applied to the lamp, and which has

no opening except the hole at the bottom, where it rests on the glass-holder ; but any other form, as a lotus-glass or vase, may be substituted at pleasure.

Fig. 3. Fig. 2.

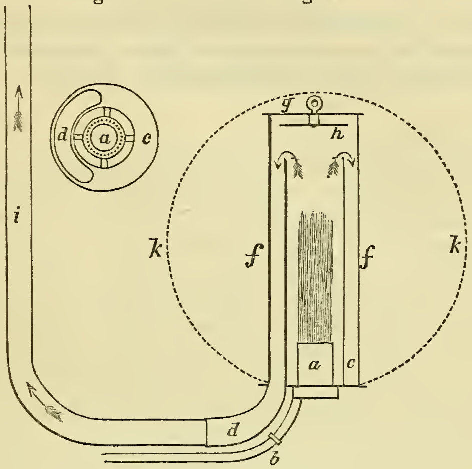


Fig. 3 is a plan of the glass holder, showing the burner, *a*, in the centre perforated with jets, with openings around it to allow of a free admission of air to the flame, and the aperture, *d*, which opens into the mouthpiece connected with the metal chimney, *i*.

The burned air and results of combustion take the course indicated by the arrows, and are entirely carried away by the chimney.*

It may be observed, that, unless the flue of this lamp is connected with a flue having a draught, it will be necessary to heat the ascending part of the tube to

* See Account read at the Meeting of Civil Engineers, June 13, 1843, for a full description of these arrangements.

produce a downward draught. In either case, the tube should be fitted with a proper valve for controlling the ascending current. *

---

* For the composition of oil, wax, tallow, and carburetted hydrogen, and tables of the comparative value of different lamps both in economy and quantity of light, see Appendix, Nos. IX. and X.

CHAPTER VI.

VITIATED AIR.

Carbonic Acid, if pure, may produce Death by Suffocation. — If diluted, by poisoning. — Mr. Coathupe's Experiment. — Accidents from Inhalation of Fumes of Charcoal. — One per cent. of Carbonic Acid in Atmospheric Air renders it unfit for Respiration. — Carbonometer. — Carbonic Oxide a Product of Combustion. — Its Effects on Birds. — Hydro-sulphuric Acid Gas, or Sulphuretted Hydrogen. — Exceedingly energetic. — Supposed by Dr. Gardner to be the Cause of Fever and Ague. — Sulphurous Acid Gas. — Evolved during Combustion of Brimstone. — Chlorine Gas. — Irritates the Lungs, when respired. — Should be used with Caution in Sick-rooms. — Mechanical Impurities. — Miasm. — Agents which may destroy contagious Miasm. — Cold. — Heat. — Smoke from Gas Manufactories. — Steam-planing Mills, Glasshouses, &c. — Dr. Reid's Definition of Smoke. — Enumeration of its Constituents.

In the chapter on respiration, we have pointed out some of the impurities which may be poured into the air of our dwellings by that process; but there are others, arising from other sources, sometimes little suspected, although they may produce injurious or even fatal effects upon those exposed to their influence. The causes of these impurities should be known, and, if possible, their amount determined, if we would act upon a rational plan in our attempts to destroy or remove them.

The following are the gases most intimately connected with our subject: —

Carbonic acid,
Carbonic oxide,
Hydrosulphuric acid,
Sulphurous acid,
Chlorine.

CARBONIC ACID.*

We are most frequently exposed to the influence of this gas, and probably a greater number of fatal results are produced by it than by all the others. It is evolved from burning fuel, from lime-kilns, brewer's vats during the fermentation of beer, in closely covered wells, and coal-mines. It is also, as we have seen, the product of respiration, and its accumulation from this is quite as fatal as when derived from either of the other sources.

Some discussion has arisen among physiologists as to the cause of death from exposure to carbonic acid, whether it is simply by suffocation, or whether the gas acts as a poison. It would seem that the different effects depend upon the purity of the gas. If quite undiluted, the organs of respiration are so strongly irritated, that the glottis closes spasmodically, and inspiration is completely prevented; consequently, when a person enters a beer-vat or long closed well, he falls at once from suffo-

* The physiological effects of deleterious gases have been drawn principally from Dr. Christison's work on Poisons, and the valuable researches of M. Felix Leblanc on Confined Air, Annales de Chimie et de Physique, 1842, to which the reader is referred for a detailed account.

cation, dying before any influence can be felt from the poisonous qualities of the gas. When carbonic acid is largely diluted with atmospheric air, the effects are entirely different ; if pure, it produces violent and irregular convulsions of the whole body, and perfect insensibility, followed by fits of spasms like tetanus, and finally death. These symptoms, it should be remembered, are produced even when a light continues to burn, and when there is no smell nor taste ; hence, the usual test of the lighted candle for carbonic acid in wells should not be too much relied on.

These cases of poisoning from pure carbonic acid are rare, compared with those occasioned by the products of combustion, which contain, besides carbonic acid, carbonic oxide, and carburetted hydrogen. One of the best accounts of the symptoms of poisoning is given by Mr. Coathupe, of England, in his account of an experiment with a stove in vogue at the time, which it was alleged did not require a chimney, as the fuel would burn without contaminating the air ; this fuel was neither more nor less than a kind of charcoal. In four hours after placing the stove in a room of the capacity of eighty cubic yards, Mr. Coathupe had slight giddiness ; in five hours and a half, intense giddiness, the desire to vomit without the power, great muscular prostration, a sense of distention of the cerebral arteries, agonizing headache, but no sense of suffocation. At this time he could with difficulty remove the stove, and in seven hours was unable to tell what was the matter with him, although conscious,

and then slowly recovered.* In November, 1838, two men were poisoned by the gases from charcoal, in one of the halls of Harvard College. They slept in a small room, twelve feet long by ten feet wide and eight feet high; before going to bed, an iron kettle, containing a quantity of ignited charcoal, was placed in the room, and the door closed. About four o'clock on the following morning, they were discovered breathing heavily, with livid and bloated countenances, and without any signs of sensibility. The lamp which stood upon the table was still burning. In the course of the day, they were made to breathe oxygen gas, and electricity was used in various ways, but without arousing them; on the following day, one had so far recovered as to be able to sit up, but the other never revived, and died on the fourth day.†

* This stove was called the Joyce stove by its inventor. It produced similar effects in a number of instances, and in one case, where two of them were used to warm a church, seventy persons were affected in a manner similar to that mentioned.

† The following account is given by a person who determined to put an end to his existence by poisoning with charcoal. He wrote down his sensations as they were perceived.

" I light my furnace, and place my candle and lamp on the table with my watch. It is now 15 minutes past 10. The charcoal lights with difficulty. I have placed a funnel on each furnace to aid the action of the fire. 20 min. past 10. The funnels fall; I replace them; this does not go to my satisfaction. The pulse is calm and beats as usual. 10 h. 30. A thick vapor spreads itself by degrees in the chamber. My candle seems ready to go out. My lamp does better. A violent headache commences. My eyes are filled with tears; I have a general uneasiness. 10 h. 40. My candle is extinguished, the lamp still burns. The temples beat as if the veins would burst. I am sleepy. I suffer horribly at the stomach; the pulse beats 40 per min.

It should be borne in mind that complete closure of an apartment is not necessary for the action of carbonic acid; for poisoning has occurred even where a window had been left partially open.

Fresh wood has the property of absorbing oxygen; dry wood which has been moistened absorbs oxygen very rapidly from the air, and produces carbonic acid. When villages situated on the banks of rivers become inundated by floods, this property of wood gives rise to much disease. All parts of the wood-work of the buildings become saturated with water, which evaporates slowly, exposing them for a long time to this slow species of combustion.

It is probable that the gases escaping from a candle just extinguished are more fatal than would be due to carbonic acid merely. A party of persons carousing amused themselves with holding a candle, just extinguished, under the nose of a boy who was sleeping in the corner of a room. At first, he aroused a little each time; but when the amusement had been continued half an hour, he began to breathe laboriously, became epileptic, and died on the third day.

Analysis of artificial airs has led to the conclusion,

---

10. 50. I am suffocated. Strange ideas present themselves to my mind. I can hardly breathe. I shall not live long. I have symptoms of madness. [Here he confounds the hours with the minutes.] 10 h. 60. I can hardly write; my vision is disturbed; my lamp flickers; I did not believe we suffered so much in dying. 10 h. 62 m. [Here were some illegible characters.]" — London Medical Gazette, Feb. 1837. Liebig, Agricultural Chemistry, p. 24, 3d edition.

that, judging from its effect upon animals, a man may breathe a considerable quantity of pure carbonic acid without immediately sinking under its effects. In an atmosphere containing five or six per cent. of carbonic acid derived from respiration or combustion, the flame of a candle is extinguished; and although life may continue for a time, the breathing becomes painful. Miners and others gradually accustom themselves to an atmosphere containing an increasing amount of carbonic acid, which would destroy a person suddenly entering it without such preparation ; but even with miners frequent accidents occur, showing that no dependence can be placed upon any presumed immunity from danger owing to this habit.

In the North of England, miners are in the habit of burning the small unmerchantable coal at the mouth of the pit, to get rid of it. The coal thus burned has been estimated by Dr. Buckland to amount to millions of tons, annually. The carbonic acid and other gases drift along the surface of the earth, and, if the wind is in a certain direction, the houses of the pitmen, and the air-shaft which supplies the mine, may have no other air than that which is contaminated by these gases. The report on the sanatory condition of the northern coal-mine district says, — " Many cases were met with where perpetual headache occurred in the vicinity of coal-pits, which the complaining parties stated continually hung upon them, except when they left the *pit-rows* in which they suffered, and went to more elevated ground. Even women, who never descend into the mines in this

district, complained of the perpetual headache which oppressed them in the vicinity of some of the pits."

We have before shown, that, although carbonic acid is a much heavier gas than atmospheric air, it does not, from this cause, fall to the floor, but is equally diffused through the room. If the gas is formed on the floor without change of temperature, this diffusion may not take place rapidly. In the celebrated Grotto del Cane, carbonic acid escapes from the floor, and rises to a certain height, which is pretty well defined to the sight on the walls; below this line a dog is destroyed, as if in water; above it, he is not affected. An analysis of the air above and below a brazier has been made, and it was found equally contaminated, — the former containing 4.65 per cent., and the latter 4.5 per cent. of carbonic acid. From the experiments of M. Devergie, who has devoted much attention to the poisonous effects of these gases, it appears that the heat disengaged from the combustion of charcoal produces an equable mixture at all elevations in the apartment, and this state of things continues as long as the room remains warm; but after twelve hours or more, the carbonic acid sinks, and while that near the ceiling contains only a seventy-eighth, that near the floor contains nearly four times as much, or a nineteenth; this may account for the discrepancy in its effects upon different individuals. This, it will be perceived, occurs when the amount of carbonic acid is excessive, one fiftieth of the whole amount of air, supposing it equally distributed, and after twelve hours.

It has been determined from experiments on animals, and from its observed effects upon men, that an atmosphere containing one per cent. of carbonic acid must be considered as injurious, and requiring immediate ventilation. When air has been rendered impure by the gases evolved from burning charcoal, a much smaller proportion of carbonic acid is indicative of danger.

Although other causes may combine to injure the air of a room in which many persons are respiring, it is an undoubted fact that carbonic acid always exists in such an atmosphere, increases with the impurity, and thus becomes an index of its amount. The greater the amount of this gas, the more urgent the necessity for ventilation.

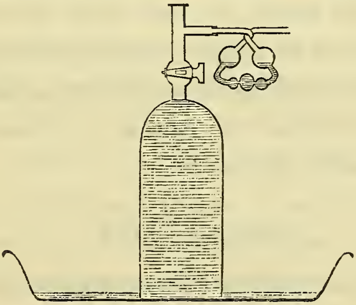
It is a matter of some importance, both in a scientific and practical point of view, to be able to determine the proportion of carbonic acid existing in any air. When we are in a room the air of which is gradually becoming impure, we are not aware of it from our own sensations, unless it has gone to the extent of producing headache or weakness of the limbs; but we can always make a close approximation to the degree of impurity by means of substances which absorb the carbonic acid and render the compound visible. This is done by the use of lime-water, or better by water in which the earth barytes has been dissolved.* If a portion of either of these fluids be

* Lime-water is made by slaking four ounces of fresh-burnt lime in a gallon of boiling water, and agitating it. After it has stood for a time, the greater part of the lime (for only about ten grains to the pint

placed in a vessel into which air can be blown from the lungs through a tube, it becomes immediately turbid from a precipitate formed by the union of the carbonic acid of the expired air with the lime or barytes in solution, thus producing an insoluble precipitate of the carbonate of these substances. A ready mode of testing the presence of carbonic acid is to fill a phial with pure water; on emptying it in the room to be examined, pour a small quantity of the test liquid into the empty phial, and shake it a moment; the turbidness will indicate the amount of impurity.

Dr. Reid has recommended an instrument called a carbonometer, by which we may ascertain accurately the amount of impurity. It consists of a tall, bottomless bottle (see fig. 4), with a tube and stop-cock

Fig. 4.



is dissolved) will settle to the bottom, and the clear liquid may be poured off and corked up for use. If left exposed to the atmosphere, it acquires a film of carbonate of lime from its union with the carbonic acid of the atmosphere. Barytic water may be made by dissolving the earth in cold water, allowing it to settle, and pouring off the clear liquid. The same precautions should be taken to exclude the air as in the lime-water.

inserted into the usual opening at the top, the extremity of the tube being fitted with a stopper, and having a bulbed tube attached to its side, or, what is better, a Liebig's tube, which is composed of five bulbs blown upon the same tube, as represented in the figure. This tube is to be filled with a solution of lime or barytes, leaving a small bubble of air in each bulb. The air, in passing through this apparatus, is much more perfectly exposed to the liquid it contains than in a single bulb.

When we wish to make an observation, we fill the bottle with water, by immersing it while the stop-cock is open, or by exhausting the air from it, and then close the stop-cock. A quantity of test water is placed in the bulbs, and the water allowed to descend slowly into the bottle, drawing the air after it through the bulbs. By graduating the bottle, we may know how many cubic inches of air have passed through the test fluid, and, collecting and weighing the precipitate, either in or out of the bulb, calculate the amount of carbonic acid by a table of chemical equivalents.

CARBONIC OXIDE.

Carbonic oxide differs from carbonic acid in its chemical constitution; it contains but half as much oxygen to the same amount of carbon. Its weight is but one grain less to the cubic inch than atmospheric air, while carbonic acid weighs one third more than air. Unlike carbonic acid, it burns, when inflamed by a candle, with a

pale blue flame ; it is that which we see flickering over our anthracite coal-fire, when burning slowly, and which appears at the top of furnace-chimneys. In this latter instance the gas is heated sufficiently hot to burn, but does not meet with enough oxygen until it reaches the external air at the chimney-top, when it is immediately transformed into carbonic acid. It is one of the gases escaping during the combustion of charcoal ; but its injurious effects upon animal life have not until lately been clearly recognized. M. Leblanc ascertained, that, when carbonic oxide constituted four or five per cent. of the air, it instantly proved fatal to a sparrow ; one per cent. destroyed a fowl in two minutes. A gentleman who inhaled it two or three times was seized with giddiness, tremor, and an approach to insensibility, succeeded by languor, weakness, and headache of some hours' duration.*

Water absorbs about one fiftieth of its bulk only ; it does not produce a precipitate with lime-water.

HYDRO-SULPHURIC ACID GAS.

This gas is distinguished from all others by its offensive taste and odor, which resembles that of rotten eggs, or some of the sulphurous spring-waters. According to experiments made by Dupuytren and Thenard, atmospheric air containing $\frac{1}{1500}$ is instantly fatal to a small bird, $\frac{1}{1000}$ destroys a middling sized dog, and $\frac{1}{250}$, a horse. Instances of its poisonous effects are not unfrequent

* Annales de Chimie et de Physique, 1842, p. 261.

among those employed in removing the filth from the Parisian privies. When it exists in a large quantity, the individual falls suddenly down, becomes insensible, and dies immediately, unless withdrawn at once from the influence of the poison. When diluted, its effects vary ; in some it produces a tendency to sleep, and an entire loss of recollection, on recovery, of all that happened after the accident ; in other cases delirium exists, followed invariably by difficulty of breathing, convulsions, and death. In slighter exposures, there is sickness, with colic, and indefinite pains in the chest, with a disposition to sleep.

Of late, physicians have suspected a close connection between it and *malaria*. In the American Journal of Medical Sciences for 1843, Dr. Gardner, of Hampden-Sidney College, attempts to show that it is the active agent in producing fevers in malarious districts, whether upon the seaboard or in the interior. He made numerous experiments, by suspending carefully cleaned pieces of coin in the water of rivers, marshes, and springs ; an indication of its presence would be had in the staining of the coins, and it was found to take place in the marshes and springs in twenty-two hours; in the rivers, especially if deep, it required a month ; but in all cases it was ultimately stained.

Dr. Gardner supposes that the reason why malaria does not exist about marshes near Boston, Massachusetts, is that iron or zinc, or other metals, exist in the subsoil, which unite with the sulphur and prevent the

development of sulphuretted hydrogen. But this would hardly explain its former prevalence in that part of New England, since the subsoil has not probably changed its character.

Parent-Duchatelet has shown, in his work on Hygiène Publique, Vol. I., p. 349, note, that some diseases are aggravated to a remarkable degree by the presence of sulphuretted hydrogen in the wards of hospitals ; so obvious is the effect, that it may be made a test of the class of complaints to which he refers.

Dr. Christison noticed, that daily exposure to it in a minute quantity caused, in a few weeks, an extraordinary lassitude, languor of the pulse, and defective appetite ; many of the workmen in the Thames Tunnel died from this cause. In England, twenty-two children were poisoned, apparently by the escape of this gas from the cleanings of a sesspool which had been thrown upon their play-ground.

It has the property of blackening carbonate of lead, and it is its presence in the emanations from privies acting upon this substance that discolors the paint. The best test of its presence, when diffused in the air, is the moist *white-lead* of painters, spread upon white paper ; it is soon discolored, even when the quantity of gas does not exceed $\frac{1}{20000}$ of the volume of the air.

SULPHUROUS ACID.

This is another of the gases produced during the combustion of charcoal, and it is not impossible that some

of the supposed effect of carbonic acid may be owing to it. It is only in connection with other impurities, and when much diluted with them, that it becomes poisonous, since, when pure, it is so exceedingly irritating, that it produces violent spasm of the upper part of the windpipe, and closes it, producing death by suffocation. The cough and uneasiness of the chest which it occasions must have been often experienced by those who use common brimstone matches, or are exposed to the smoke of anthracite coal. Dr. Turner ascertained that in its effects upon vegetable life it was hardly less energetic than hydro-sulphuric acid. It reddens, and afterwards bleaches, litmus paper ; hence, it might be used as a test, where the quantity is considerable.

CHLORINE GAS.

It is generated in large quantities in bleaching establishments ; it is also freely used in fumigation of sick-rooms. It has the property of destroying the volatile principles given off by decaying animal matter, by uniting with their hydrogen, and probably has a similar influence on contagious effluvia. It is exceedingly irritating, even in the minutest quantities, producing inflammation in the lungs and air-passages. A young man who breathed it as an experiment experienced violent irritation of the air-tubes, cough, tightness, sense of pressure on the chest, and difficulty of breathing.

From the manifest effects of this gas upon those exposed to its influence in bleacheries, and from the facts

just mentioned, physicians and the attendants upon the sick should be warned against using it so freely as is sometimes done ; we have little doubt that to those with weak lungs it has often proved decidedly injurious, and may have been sufficient to decide fatally the case of those already suffering from inflammation of these organs.

In some instances, it is by no means improbable that the chlorine is more injurious than the effluvia it is employed to remove. It is also a question, whether it is not quite as well to remove the offending substance, and submit the apartment to a current of fresh air, as to remove merely the indication of its presence. There can be no question, that so irritating a gas should be used as seldom as possible, and with great care, in the rooms of the sick, and indeed wherever it may enter the organs of respiration.

MECHANICAL IMPURITIES OF THE AIR.

There are other gases and vapors, evolved in the various processes of the arts, which are injurious ; but these processes, in this country, have not been carried on to an extent sufficient to produce serious effects. Formerly, muriatic acid gas was allowed to escape from manufactories in sufficient quantity to produce a deleterious influence upon the vegetation and animals in their vicinity ; even when discharged from a lofty chimney, it has been tested in air at the distance of two miles. It is now

condensed by water, and applied to a useful purpose in the arts.

Impurities arise from the volatilization of metals, or from their oxides, in the form of an impalpable powder. In this way, mercury, lead, and copper may be introduced into the system through the lungs and skin, in sufficient quantity to produce their specific effect.

In Paris, not long since (see Annales d'Hygiène Publique, No. 24), traces of verdigris were found in food which was hung over the fire in an uncovered vessel, and its origin was believed to have been the copper chimney of a neighbouring steam-engine. Particles of the copper, it was supposed, had been transported, by the ascending current and wind, over the chimney, into which it fell.

The arsenic and other metals, sometimes used in the hardening and coloring of candles, give rise to injurious vapors during their combustion. In the Annales d'Hygiène Publique will be found a list of substances which may be used for coloring such articles, and which evolve no pernicious products.

The vapor from the boiling of varnish containing gum copal, although it may not be injurious to the health, certainly renders the air offensive for a great distance to the leeward of the place where the operation is carried on. We have perceived the odor arising from it a mile and a half from the manufactory.

The foul air escaping from the openings in drains is, in cities, a fruitful source of offensive, and, if they con-

tain, as they frequently must, any of the three gases first mentioned, unhealthy smells. In Strasbourg, a few years ago, a family of five was destroyed by the foul air which had escaped from this source, and been diffused over the house, and into the rooms where these persons slept.

Whoever has noticed the motes floating in a sunbeam must be well convinced that even the best air contains a large amount of mechanical impurities. The dust from roads must afford a large supply, as well as the pollen and minute spores of the smaller plants. In a large city, the sources of mechanical impurities can hardly be pointed out, they are so varied in their nature ; the impalpable dust from coal, and that from the streets, together with the unconsumed particles of coal, especially if it is of the bituminous character, must form a great amount.

We have known persons who have been engaged in carrying or breaking coal to expectorate phlegm still blackened by the dust, four or five weeks after leaving their employment. The influence of the gritty and irritating particles detached in the grinding of cutlery is well known. The form of disease induced by this cause is peculiar ; it produces inflammation, first, of the larger air-tubes, and then of the minute portions of the lungs, accompanied by frequent cough and asthma. Very few of the operatives employed in this branch of business pass the middle period of life.

In a thorough system of ventilation, in a city, one of the first requisites is to obtain air as free as possible from

any of the impurities above mentioned; if the air is still objectionable on this account, it must be subjected to such processes as will sift them out or precipitate them from it.

MIASM.

Under this head we include all those unknown causes of disease which occasion epidemics and contagions, the effluvia from marshes and from human bodies, producing, in the one case, fever and ague, and in the other typhus. These causes may float in the air to a distance from their source, and, when they convey disease, invariably reproduce that from which they are derived. Of this nature are the causes of small-pox and measles ; these diseases have always been true to themselves ; in no case has one been transformed into the other. It is probable, however, that the causes of epidemics do not exist in the air alone; it may be that they are derived from the soil, or the system may require several years of preparation before the subtle agents in the air can find subjects for their propagation.

Whatever may be the nature of miasm, we know that certain states of the atmosphere favor its propagation ; in most instances, a warm, moist state is that which is most favorable to animal and vegetable decomposition, and it is doubtless from this process that many impurities are derived. A degree of cold sufficient to freeze will put a stop to all kinds of decomposition and the impurities derived from it, and it is not probable that many kinds of contagion are active after being exposed to

the heat of boiling water. Some chemical agents have an influence over the effluvia of contagious diseases, and destroy their power of propagation.

According to Liebig, ammonia is very generally produced in cases of disease ; it is always emitted in those in which contagion is generated, and is an invariable product of the decomposition of animal matter. The presence of ammonia in the air of chambers in which diseased patients lie, particularly those afflicted with a contagious disease, may be readily detected; for, if it be present, the moisture condensed on vessels filled with ice produces a white precipitate with a solution of corrosive sublimate. This is the usual test for ammonia.*

SMOKE.

In England, attention has been strongly drawn to the amount of smoke emitted from the chimneys of some of the manufactories, and a committee was appointed by the House of Commons to inquire into the means and the expediency of preventing the nuisance of smoke arising from fires and furnaces. During the sittings of this committee, distinguished chemists, engineers, and leading master-manufacturers were called before them, and their views and opinions embodied in a report, with minutes of evidence, printed in August, 1843.

Over London, in calm weather, the smoke hangs like

* Liebig's Chemistry of Agriculture and Physiology, 4th Cambridge edition, p. 408.

a cloud, and when there is a wind, it is drawn out by it into a stream extending twenty or thirty miles from the city. So constantly are the black particles, or *blacks*, as they are called, falling, that the number of days sheep had been in Regent's Park could be determined by the blackness of the wool. There were counted on a single piece of paper, three feet long and two feet wide, in the neighbourhood of the Houses of Parliament, 2,000 blacks, which had come through an open window, and had been deposited in the course of a single morning. Vegetation in the vicinity of large cities, as London and Manchester, it is said, is seriously injured, and in some instances the trees are destroyed, by the coating of carbonaceous matter with which they are covered.*

In this country, on account of the consumption of wood and anthracite instead of bituminous coal, we are not annoyed by smoke to the same extent as the English; still, those who are situated near *gas manufactories*, and steam-planing and sawing mills, and glass furnaces, cannot but feel its influence. The unburnt carbonaceous matter, carried up by the heated air, falls at a distance proportioned to the force of the wind. If breathed with the air in which it floats, it is deposited in the lungs, and, like all foreign substances, produces, if long continued, disease of their lining membrane. It falls upon the roofs of houses, and enters the rain-water cisterns; it collects upon clothes exposed to dry, and enters open windows. During light

* Report on Smoke Prevention, pp. 64 and 80.

rains, soot, from these sources, is precipitated with the drops, and, if it happen to fall upon clothing, can be removed only by washing. The effect upon works of art and nice furniture is injurious, and the labor of cleaning greatly increased. We much question whether any manufacturer or corporation should be allowed to produce such an amount of evil, while ways exist of effectually preventing it, and when these ways are attended with a saving of fuel proportioned to their successful operation.

At the request of the Committee of the House of Commons on Smoke Prevention, Dr. Reid gave a definition of *smoke*, of which the following is an abstract.

The term smoke, applied in common language to any sooty exhalation or steam, includes a great number of products, ever varying, according to the nature of the materials from which it proceeds, and the manner in which these materials are subjected to the action of heat and air, and mingled with other substances.

1. *Black smoke* consists essentially of carbon, separated by heat from coal or other substances, with carbonic acid and carbonic oxide; if the heat accompanying its production is great, the carbon forms a very loose and powdery soot; if less, the larger the amount of the following substances: —

Carbon,
Water,
Resin,

Oily and inflammable products of various volatilities,
Ammonia,
Carbonate of Ammonia.

2. When the carbon, oils, resin, and water are associated together in certain proportions, they constitute *tar*. *Soft pitch* is produced, if the tar be so far heated that the water is expelled; and *hard pitch*, i. e. *resin* blackened by the carbon, when the oils are volatilized. A further heat resolves the pitch and oils into permanent gases and carbon.

3. In all cases of ordinary combustion, the gases or other bodies containing carbon unite with the oxygen of the air and form carbonic acid, and this passing over red hot cinders will be deprived of one portion of its oxygen, and become carbonic oxide, and another portion of carbonic oxide will be produced by the union with carbon of the portion of oxygen lost by the carbonic acid.

If carbonic oxidepasses to the external air at a proper temperature and meets with sufficient oxygen, it burns with a pale-blue flame, and is converted into carbonic acid.

4. Black smoke is always associated with carburetted hydrogen gases, composed of carbon and hydrogen in various proportions, and when in a state of combustion, they constitute flame. When the draught of a furnace is powerful, minute fragments of raw coal occasionally appear in the smoke. This is very frequently the case with anthracite coal; when thrown upon the fire, it does not melt together like the bituminous, but breaks into

minute portions, which are often thrown out of the chimney, especially where the fire is urged by a fan.

5. The smoke from charcoal, coke, and anthracite is always invisible, if the material be dry ; nothing but carbonic acid or carbonic oxide gases being formed, and either the one or the other of these, according to the supply of air. A flame may appear, however, if carbonic oxide be formed, by part of the carbon as yet unconsumed decomposing the carbonic acid.

The gases escaping in all these cases are mixed with the nitrogen of the air, which never undergoes combustion.

6. Wood-smoke is rarely black, the large amount of gases evolved passing away before they can be subjected to that intensity of heat which alone produces thick black smoke. Water and carbonic acid are the products of the full combustion of the wood, omitting the ashes. Pyroligneous acid is formed during the destructive distillation of wood, whether made in an open fireplace or a covered vessel ; it is strongly acid, and produces the irritated and inflamed state of the eyes when exposed to smoke. In cold weather, especially when this acid is formed in *air-tight stoves*, at a low temperature it is condensed upon the bricks of the chimney, and, uniting with the lime, forms an acetate of lime, which is soluble in water, and, being gradually removed by the rain, nothing remains between the bricks but the sand. This is a very common result in new chimneys. Where it does not go to the extent of destroying the adhesion of the mor-

tar, it finds its way through the chimney and runs down, staining the walls and becoming offensive by its odor.

7. Sulphureous smokes are evolved from copper works and from gas works, either in a visible or invisible state.

8. Metallic smokes are produced in manufactories where ores of lead, copper, arsenic, and other metals, are used ; they then float in the other gases, as we have before mentioned under the head of Mechanical Impurities of the Air.

The following statement shows the general amount of air required for the combustion of 100 tons of coal, supposing it to contain 84 per cent. of carbon, 6 per cent. of hydrogen, and 10 per cent. of nitrogen and other substances.

Eighty-four tons of carbon require 1,012 of air (224 tons of oxygen + 788 of nitrogen), and produce 308 tons of carbonic acid, the nitrogen remaining unconsumed. Six tons of hydrogen require 216 of air (48 tons of oxygen + 168 of nitrogen), and produce 54 tons of watery vapor, which passes off with the 168 tons of unconsumed nitrogen. This calculation is founded upon the supposition that all the oxygen is consumed, which is very far from being the case ; much air passes through and over the fuel without coming into immediate contact with it.

CHAPTER VII.

OF PREVENTING AND REMOVING IMPURITIES OF THE AIR.

Chemical Agents for removing Causes of Disease.— Lime-washing. — Sulphurous Acid removed by Water. — Section of Fire-place for destroying Impurities from Boilers. — Duchatelet's Mode of ventilating the Parisian Sewers. — Mr. Jeffreys' Plan for precipitating Smoke. — Thomas Hedley's Estimate of Water required for Precipitation. — Dilution. — St. Rollox Chimney. — Combustion of Emanations from Drains. — Combustion of Smoke. — Its Principles. — Its Economy. — Smoke may be entirely consumed. — Chanter's Smoke-consuming Furnace. — Williams's Plan. — Filtration.

The contrivances for preventing and removing impurities are numerous and varied, but they may be arranged under four classes, — by chemical agents, combustion, precipitation, and filtration; their evil effects may also be diminished by dilution.

Chemical Agents.—We have said that ammonia is very generally produced in cases of disease, and especially in contagious diseases. It is stated by Liebig, that, by evaporating acids in air contaminated by such causes, the ammonia is neutralized, decomposition is arrested, and the contagious power destroyed. Muriatic, acetic, and sometimes nitric acids, have been preferred by Liebig before all others for this purpose.*

---

* Liebig's Chemistry of Agriculture and Physiology, p. 409.

Sulphuretted hydrogen (hydro-sulphuric acid) may be removed by burning sulphur, and thus forming sulphurous acid (which may be absorbed by water), or by evaporating nitric acid in the contaminated air.

Carbonic acid may be withdrawn by the use of an alkali, or by a caustic earth, for which it has a strong affinity; for this last, lime, in the form of *whitewash*, is most commonly used.

The efficacy of lime as a purifier depends upon its freshness and causticity; if old, it has already absorbed or rather decomposed all the impurities it is capable of, and becomes inert. When fresh, it absorbs carbonic acid from the air of the room, forming a carbonate of lime upon the walls; it has also, in virtue of its causticity, the property of destroying vegetable growths of all kinds, and the various animalculæ which flourish so wonderfully in neglected and dirty houses. The celebrated John Howard, when in a lazaretto near Venice, lost his appetite, and thought himself in danger of the slow hospital fever. His room, which was dirty, had been repeatedly washed with boiling water without removing the offensive smell. One morning he got it lime-washed, when it immediately became sweet; on the following day it was dry as well as sweet, and "thus," says he, "at a small expense, and to the admiration of the other inhabitants of this lazaretto, I provided for myself and successors an agreeable and wholesome room, instead of a nasty and contagious one."*

* Howard on Lazarettos, p. 11.

The cleanly appearance which it gives is not the least of its recommendations ; its usefulness as a means of purification cannot be too strongly insisted upon.

Sulphurous acid may be readily removed by the use of water, which absorbs thirty-three times its volume. Hence, passing the air through a shower of water, or simply sprinkling the floor of a room, will readily remove it.

During the cleansing of the sewers of Paris, of which a full and interesting account is given in the work of Parent-Duchâtelet, in addition to the aid derived from combustion conducted in a large chimney placed over one of the openings of the sewers, advantage was taken of a mixture of one pound of black oxide of manganese and two pounds of hydrochloric acid in an iron kettle hung in the chimney. A constant disengagement of chlorine went on, which seized in its passage the fetid gases, decomposed them, together with the sulphuretted hydrogen so common in these places, and rendered them entirely harmless.

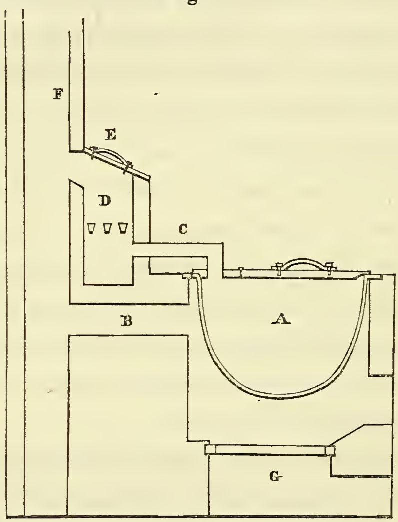
Combustion is a powerful mode of destroying many of the impurities produced in the processes of the arts, and arising from sewers ; it is one that can often be applied with slight expense to the proprietors, — an important consideration in all cases where we wish a regular and constant accomplishment of the object.

Some of the offensive vapors, like those from the manufacture of copal varnish, are inflammable, and may be used in supplying the fire required under the boiler ; the

same is true of smoke. The saving of fuel in such cases may, in some measure, compensate for the expense of fitting up the necessary apparatus.

The simplest mode of drawing emanations from boilers through fires is that of fitting a cover to the vessel from which the impurities escape, and leading a pipe from that to a chimney, into which it enters beneath a small fire kept constantly burning. In fig. 5, A rep-

Fig. 5.



resents the boiler with its cover; G, the grate; B, the smoke-flue, passing to the chimney, F; C, a pipe connecting the boiler with a small fireplace; D, its grate, through the fire on which the impurities pass on their way to the chimney; E is the door through which the fire on the grate, D, may be replenished. In this plan the cover may be readily raised to attend to the process,

and through an opening in the cover any thing that may be necessary to stir the contents of the boiler may be introduced.

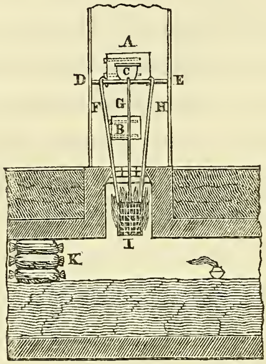
The pipe could be carried downward, and be made to enter the ash-pit, and pass through the fire on its way to the chimney. This would obviate the necessity of a special fire. In this case, all the air for the fire could be drawn over the contents of a boiler through an opening in the cover ; if the vapor is inflammable, fine wire-gauze placed in the pipe would prevent the passing of the flame, on the same principle as in the Davy lamp.

Parent-Duchâtelet, during his labors in clearing the sewers of Paris,* used a chimney of sheet-iron, four feet in diameter, and seventeen feet and a half in height, with suitable handles, so arranged that it could be carried by four persons. On one of the sides were two openings, fitted with doors, A, B (fig. 6), thel ower one for feeding the fire, and the upper for introducing fumigating substances to the iron vessel, C. Between the two doors are two transverse iron bars, D, E, with two others crossing them at right angles. To these bars, by means of iron rods, F, G, H, the grate, I, is attached ; the length of the rods allowing it to hang as low as the upper surface of the sewer. The bags at K are filled with sand, and intended to cut off all communication with other parts of the sewer. The air was admitted at one of the street openings, and passed by the workmen on its way

* Some idea may be formed of the importance of these common sewers, and the labor required in clearing them, from the fact, that, in 1836, they were more than 233,300 feet in length.

to that over which the chimney was placed. The combustible used was light wood, cut into small pieces, and sometimes, when a quick fire was required, shavings of wood were added. It was found that a blaze was necessary to produce a full effect in the chimney.

Fig. 6.



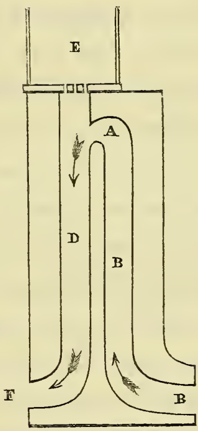
The velocity of the air was ascertained by producing smoke and noting the time required to pass a certain distance. The time usually required to traverse the sewer and chimney, the whole being 345 feet, was from two minutes to two and a half; the area of the sewer was twenty-six square feet ; consequently the whole quantity passing from the chimney in two minutes and a quarter, the mean of the two times just mentioned, was 8,970 cubic feet, or sixty-six cubic feet per second. This, however, is not exact, since the chimney has not the same area as the sewer, and the resistance offered by the walls of this last would reduce the quantity slightly.

A fan was sometimes used, revolving in a drum as usual, but its action was not as equal, nor as effectual, as

that of the chimney ; it required four men for its regular performance, each man working but ten minutes, or at most twelve, at once. The workmen in all cases preferred the chimney to the fan.

In 1824, Mr. Jeffreys, of Bristol, invented a mode of precipitating from smoke the lampblack, metallic vapors, and other sublimated matters, by washing them with a stream of water.* Whenever the necessary supply of water can be procured, this plan is both effectual and economical.

Fig. 7.



In the vertical section, fig. 7, B B is the smoke-flue, the smoke passing in the direction of the arrows ; at A, the flue turns downward, and at the top of the vertical portion is a cistern, E, the bottom of which is perforated

* Quarterly Journal of Science, Literature, and the Arts, No. XXXVI., p. 270.

with holes, varying in size according to circumstances, but which spread over the whole area of the descending flue, D, that the shower of water constantly passing downward from the cistern may be equally diffused. The shower, in its descent, carries down with it all the smoke and all the sublimated matter which has passed from the fire, and runs off at the flue, F. This last flue may turn upwards and enter a chimney, while the liquid is allowed to pass off by a side opening, so curved that it may always remain filled with water, and prevent the smoke from passing out. These flues may be placed quite near each other, divided by a single wall, or at a distance, as may be most desirable; they may be made of brick, stone, wood, or iron, and in any direction, provided that through which the water passes is vertical.

Mr. Thomas Hedley, before a committee of the House of Commons, stated, that, by an arrangement of this kind, he was able to save, in the form of lampblack, about one twentieth part, by weight, of the coal consumed. It appears, also, that the highest flue required is about thirty feet; that the effect of a descending shower upon the draught is such as to enable manufacturers to dispense entirely with a chimney, and furnaces so arranged have been found to work well, not being subject to downward currents, or affected in any way by winds. The number of gallons of water required per minute for a forty-horse engine is between forty and fifty, falling a distance of thirty feet. To raise the water thirty feet would require less than half a horse-power,

and the expense of the erection has been repaid in one year by the lampblack and ammoniacal products, which are purchased by the farmers. In these cases, there are usually two descending flues placed side by side, half the water falling into each flue, but the whole of the smoke passing down each flue ; by this arrangement the velocity of the smoke is much increased. The same water is often pumped up, many times in succession, before it becomes rich in the deposited matters. Lime-water, or other chemical agents having an affinity for the dissolved matters, or which would produce more valuable combinations, have been suggested as a precipitant in some manufactories.*

Dilution. — The dilution of impurities is usually effected by delivering them at a great elevation, by means of very high chimneys. The gases and vapors which escape fall slowly from the top, and soon become so far diffused, according to the law of which we have so often spoken, that they are quite harmless. Many of these lofty chimneys are seen in Belgium ; but the most remarkable is that at St. Rollox, Glasgow. It was erected to carry off muriatic acid and other gases escaping from the manufacture of barilla ; it answered the purpose perfectly, but the plan of condensation we have just mentioned was soon adopted, and the importance of the chimney as a diluting agent ceased. It is now used to work various furnaces, in which 120 tons of coal are

* For further particulars, see Report on Smoke Nuisance by Committee of House of Commons, p. 130.

used daily ; and the products are drawn through flues, in some instances 400 yards in length, before they reach this immense shaft. The following are its dimensions : —

	ft.	in.
Height from surface . .	432	6
Depth of foundations . .	15	
Total height . . .	447	6
Diameter at base . . .	45	
" " surface of ground	40	
" " top . .	13	6

1,250,000 bricks were used in the construction ; they weighed 121 pounds per cubic foot, resisted 63 tons pressure per superficial foot before *cracking*, and required 110 tons to crush them. The brick work is 3½ bricks at bottom, and 1½ at top. The internal flue is 260 feet high, and its sides perfectly vertical ; consequently, the chimney is a double cone, and the heat of the gases is retained as long as possible, giving an equal temperature and a maximum velocity. Red-hot matter, *probably carbonic oxide*, has been seen projected in a column from its top, and its temperature near the top is supposed to be seldom under 600° F.*

It has been proposed that a chimney of this kind be erected in the public squares of a large city, to which flues may be conducted from all the main drains and common sewers, and a downward draught be established at all their openings in the streets and houses. It is well

* Jameson's Philosophical Journal, April, 1845, p. 216.

known that in all cities more or less offensive effluvia escape from drains, which cannot but be injurious to the health ; but even if these emanations were not injurious to the health of the inhabitants, the prevention of them would be a great gain to the comfort and the appearance of their habitations.* The shaft could be made ornamental, of sufficient height to command a strong draught, at very little expense of fuel. In private houses it is of great advantage to connect a drain from which offensive air escapes, by means of a tube, with the kitchen-flue, or any other in which a constant heat is maintained. In the building of a house, a flue could be made in contact with the kitchen-flue, that could be rendered available for this and other purposes without diminishing the draught.

Combustion of Smoke. — We have already spoken of the great nuisance of the smoke of bituminous coal, as usually burnt in large cities. A great variety of modes have been invented and patents taken out for the consumption of smoke, but, until a short time, they have all been contrived upon a wrong principle. It has been supposed that it is only necessary to heat the smoke to a certain temperature to consume it, and if it is not consumed, it is because the requisite heat had not been attained. For this reason it was proposed, and the proposition was for a long time practised upon, to place the new coal in front, near the door, and allow the gases to be driven off over the hot coals and

* These emanations destroy the beauty of all paints composed of the oxides of lead, by reducing them to the state of sulphurets.

burn. This was Mr. Watt's plan ; he admitted a quantity of atmospheric air where the coal was undergoing the process of coaking, but never sufficiently diffused to mingle with the gases and accomplish their complete combustion ; even if they were transformed into carbonic acid, still, in passing over the incandescent fuel beyond, that carbonic acid would dissolve a portion of carbon and again become carbonic oxide. This plan was not successful, nor were any others which were formed upon the same principle.

An Argand lamp without a chimney will burn without smoke, if the wick be kept low ; but on raising it to a certain point, it smokes ; if now the chimney be put on, the smoke no longer appears ; it is not produced. In the first case, the volatilized carbon and disengaged hydrogen, into which the oil is converted, do not meet with sufficient air at a proper temperature until they have risen so high that they have become too cold to burn ; in the second case, this amount of air is supplied at the right place, and the red-hot vapor of carbon unites with it and becomes invisible carbonic acid. This is precisely the principle upon which smoke is to be prevented in furnaces. Soft or bituminous coal is composed essentially of carbon and hydrogen, which, with a certain amount of heat, are disengaged as gases, and, if a proper amount of oxygen is supplied, and of a proper temperature, they unite with it and are consumed. If these facts are kept in view, it will be seen that smoke can be prevented as readily in the furnace as in the Ar-

gand lamp. If the air is introduced in too large quantity, or at too low a temperature, the gases are cooled, and smoke appears. In these cases, it is found necessary to admit the air heated to a proper temperature, without allowing it to come in contact with the fuel, and entirely separated from that which passes through the grate, that it may retain its full amount of oxygen up to the moment it mingles with the gases.

It has been supposed that the admission of air would cool the furnace and diminish the amount of steam ; but this is found not to be the case when so regulated as just to consume the smoke, as will be seen in the following results of experiments by Mr. H. Houldsworth. The kinds of coal used were Knowles's Clifton coal, a free-burning kind, which does not cake, and produces a considerable quantity of ashes ; and Barker and Evans's Oldham coal, a slow-burning, rich, caking coal, containing little ashes.*

Steam produced in a given Time.

No air admitted,	Coal thrown	upon	fire,	230	lbs.	100
No air,	"	"	"	460	"	109
53 square inches of air,	"	"	"	230	"	132
Air regulated to consume all smoke,	"	"	"	230	"	134
53 square inches of air,	"	"	"	460	"	140

Showing that the admission of air increases the amount of steam produced in a given time from 30 to 40 per cent.†

* Minutes of Evidence of Committee on the Smoke Nuisance, p. 122.

† Mr. Johnson, in his Report to the Navy Department, on Coals, gives the following as his results of the influence of the admission of air through a perforated plate just beyond the grate.

In the use of anthracite coal, a certain amount of air admitted independently of that which passes through the grate also increases the amount of heat, and so far is advisable; but with the use of this fuel there is but little visible smoke, therefore the same reasons cannot be urged for its admission as in the bituminous coal. An inconvenience attends the combustion of anthracite which does not extend to so great a distance as the smoke of soft coal, but so far as it does extend is quite

---

The advantage of open air-plates, shown by the number of pounds of water evaporated by one pound of fuel, is as follows: —

7 anthracite,	0.43 per cent.
10 free-burning coals,	2.13 " "
10 Virginia coals,	1.96 " "
6 foreign, 1 Western,	3.83 " "

The disadvantage of open air-plates, as shown in the number of cubic feet of water evaporated per hour: —

Anthracite coals,	14.9 per cent.
9 free-burning coals,	2.68 " "
9 Virginia coals,	1.48 " "
6 foreign, 1 Western,	5.37 " "

These results differ widely from those of Mr. Houldsworth, as well as those of Josiah Parkes.

We question whether this statement can be of value in estimating the effect of the admission of air; no mention is made of the state of the flues, whether they were filled with smoke, or whether they were filled with inflamed gases; there is nothing said of a spy-hole, by which the inside of the flue can be examined, or that any such was used if it existed. As far as we are able to ascertain, the air-plate was moved without any regard to the effect that the admission of air is intended to produce, — the combustion of the gases and the consequent prevention of smoke. If too much air is admitted, the furnace is cooled and smoke is produced, and the evaporative power diminished; if too little, smoke is again produced, and the same result follows; the amount must depend upon the kind and quantity of coal, and this can be determined only by experiment.

as troublesome. When an anthracite fire is urged by a very strong draught, or by a fan forcing air through the grate-bars, small portions of the coal are driven out of the chimney and carried by the wind into the neighbouring houses. This has in some instances been found to be a very serious inconvenience, and as such, in Boston, has been made the subject of investigation. We see no reason why these particles may not be precipitated after they have passed from the boiler, by the precipitating process above mentioned, or the furnace be so arranged that they may be burned before they reach the chimney.

Fig. 8.

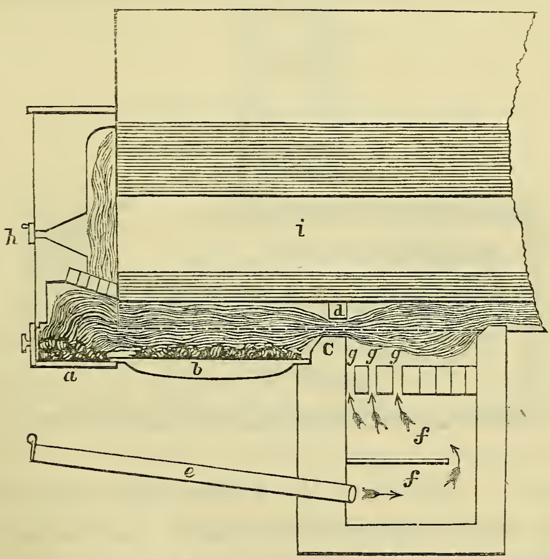


Fig. 8 is a section of Mr. J. Chanter's smoke-burner ;

a is the iron dead-plate upon which the coal is deposited and undergoes the process of coking; when a new charge of coal is thrown in, this coke is pushed forward upon the bars, *b*, which may be made movable or stationary, as shown; to this the air is admitted from the ash-pit, through the grate-bars. From the grate the gases pass on between the bridge, *c*, and the deflective brick arch, *d*, by which they are thrown down and come in contact with the air from the air-distributors, *g g g*, after it has been heated in its passage through the air-pipe, *e*, and the hot-air chamber, *f*; *h* is a sight-hole to ascertain the consumption of smoke and regulate the quantity of air admitted; *i* is the flue through the boiler.

Fig. 9.

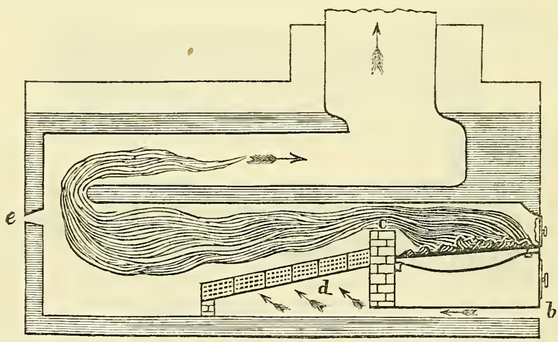


Fig. 9. Section of Mr. Charles Wye Williams's marine boiler, with its diffusion-plates. In this furnace the fuel is thrown immediately upon the grate-bars, and through them the air finds admission to it. The gases

pass over the bridge, *c* ; here they meet a current of air entering just beyond the bridge, which has been admitted by the air-tube, *b*, into the air-chamber, *d*, and from that escaped through a great number of holes in the diffusion-plate, above *d*. The force with which the air enters through this series of jets or blow-pipes enables it to penetrate into the gases and obtain the largest possible extent of contact-surfaces for the air and gas, which is important, since the time allowed for diffusion would otherwise be insufficient. *e* is the spy-hole, for ascertaining the state of the smoke.

Fig. 10.

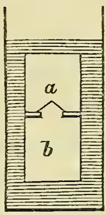


Fig. 10 is a cross-section of the diffusion-plate and air-chamber. *a*, diffusion-plate ; *b*, air-chamber.

Mr. Chanter has given plans and sections exhibiting the application of his principle to soap-boilers' kettles, and brewing-coppers. In Mr. Williams's work on the Combustion of Coal will also be found drawings of his mode of producing extensive diffusion beneath boilers and reverberatory furnaces.

Filtration. — Some of the impurities of the air are of a kind that can be removed by passing them through a porous veil sufficiently fine to sift them out. This

has been applied to the purification of air for the purposes of ventilation. In the Houses of Parliament, the blacks from coal-smoke were so annoying, that it was found necessary to put up a veil forty feet long by twelve feet deep ; on this, in a single evening, in the worst states of the weather, by counting the number of blacks upon a square inch of surface, it was ascertained that 200,000 visible portions of soot had been excluded in a single sitting.

CHAPTER VIII.

MOVEMENTS INDUCED IN ATMOSPHERIC AIR BY HEAT.

Dr. Franklin's Contrivance for studying them. — Flame of Candle, its vertical Direction. — Movement of heated Air in a Tube. — In Tubes of unequal Lengths. — In two Tubes of equal Length. — Olmsted Stove. — Of Smoky Chimneys. — Room too tight. — Cure by admitting warmed Air. — Mantel of Chimney too high. — Wind Furnace. — Two Chimneys in same Room. — Of narrowing Chimneys at Top. — At Bottom. — Opposing Currents. — Cure.

THE motions induced in the air by heat should be considered with care ; an ignorance of them has produced some of the most absurd plans of ventilation, and occasioned a useless expenditure of money in the construction of chimneys, and still more in futile attempts to remedy their defects.

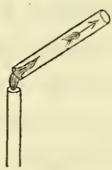
For studying this subject, Dr. Franklin suggested small glass models of rooms made of five squares of glass framed in wood at the corners, with doors, and movable glass chimneys, with openings of different sizes, and different lengths of funnel ; some of the rooms so contrived, that they could be made to communicate with each other and form combinations ; the chimneys to be heated by burning bits of wax taper ; these would be extinguished, when the flues were heated, and the course of their smoke observed. With these, all the effects of

chimneys, of draughts of air and winds, could be seen through the transparent sides. Many of the movements of heated air may be observed with a candle and a glass tube a foot long.

The force with which heated air rises is well shown by the flame of a common candle ; all the air in immediate contact with the burning gases, as well as the gases themselves, become intensely heated, are immediately pressed upward by that which surrounds it, and the flame assumes a vertical direction.

This same tendency upwards from a heated body exists in all cases, increasing with the increase of temperature. The air in contact with the human body is warmed a greater or less number of degrees, according to the difference of temperature between it and the atmosphere, — in a still air and at a mean temperature, about five degrees, it is said ; by this a constant and important circulation is maintained.

Fig. 11.

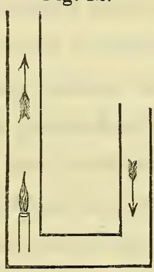


If we hold a heated tube, an Argand chimney a foot long, for instance, perpendicularly over the candle, we observe that a strong current of air rises through the tube, which may be felt above it, and that the flame is whiter and the light more intense, showing that it is sup-

plied with a larger quantity of air. On inclining the tube, as in fig. 11, the flame is inclined also, and will continue to incline until it has deviated from the perpendicular many degrees.

A piece of ice suspended in a glass tube, or a cold glass tube, will have an effect directly opposite to that of the candle; the air will begin to descend through the tube with a velocity proportionate to the difference of temperature between it and that which surrounds it. Hence we see that it is only when the heat of the air within and without the tube is the same that no motion exists. It is surprising how slight a difference is required to determine a current in one direction or the other.

Fig. 12.



The force of the current will be in proportion to the temperature and height of the heated tube. If two tubes of unequal heights be united by a third, as in fig. 12, the candle in the longer tube will overcome that in the shorter, *and establish a downward* current in the latter.

With two tubes of equal length united by a third, as in fig. 13, having a candle in each, one is soon over-

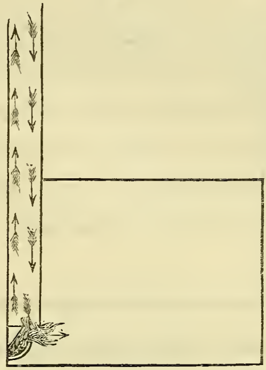
powered by the other ; and this may happen even when an opening is made in the third tube, admitting a limited

Fig. 13.

supply of air. The reason of this is, that the balancing of one portion of air against another is exceedingly delicate, and the least increase of heat in one tube above that in the other destroys the equilibrium. An illustration of this occurred in a church heated by a hot-air stove. It was proposed to obtain more radiating surfaces by carrying two smoke-pipes from the fire-place up through the church and uniting them at the top in one chimney. It was soon found that one pipe was always cold, the smoke escaping through the other ; a valve was then placed in each pipe ; but, even with the nicest adjustment of these, smoke could be made to pass through both only a few minutes at a time ; one constantly overpowered the other. The "Olmsted stove" was frequently arranged with a radiator on each side, through both of which it was intended the smoke should pass ; this it would rarely do, unless the draught of the chimney was very strong. Two *drums* are sometimes affixed to a smoke-pipe by branch pipes ; but it is seldom that the smoke can be made to pass through both.

A chimney to which less air is supplied than the fire requires, as happens in a new, tight room, often has two

Fig. 14.

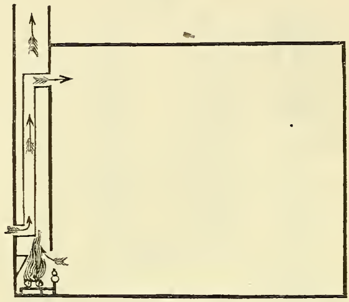


currents, as in fig. 14, one upwards from the fire, and another from the top downwards ; these two currents meeting just above the fire, part of the smoke is driven into the room. If the chimney be divided by a partition into two flues, one of which opens into the room at the side of the chimney, and the other directly over the fire, a descending current will be established in one, and an ascending current in the other, which cannot interfere, and the smoking will cease.

If the flue for introducing air be contained within the other, and made of some thin material, the lower extremity communicating with the external air, and the upper with the room, as in fig. 15, the air will be warmed by the transmitted heat, ascend through the tube as it enters the room, and not expose those in it to unpleasant draughts. Warmed air is very frequently in-

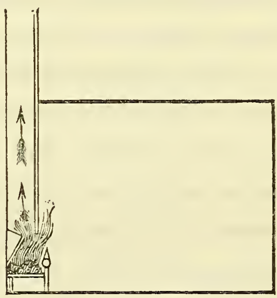
troduced into a room through a fireplace with a double back, between the walls of which the external air, in

Fig. 15.



passing, is warmed, and enters beside the fireplace. This is an excellent contrivance, and if well made will be found to answer perfectly.

Fig. 16.



When the fireplace is too high, the portion of air passing up the chimney is drawn from a large space, and the current being proportionally feeble, the flame which is usually drawn backward is left to rise vertically, and escapes into the room. The air which enters the chimney does not approach the fuel, and is consequently less heated, and the current is diminished.

If the chimney is brought down low, all the air passes near the fire, and the velocity of the smoke is increased. If the fire be laid upon a grate within the chimney, all the air passes through the fire, and we have a *wind furnace.*

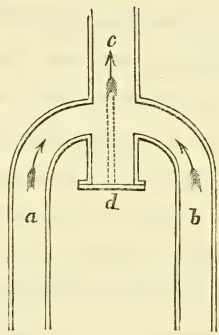
When two chimneys are in the same room, or communicate with each other through an open door, one will often overpower the other, as was represented by the candles, in fig. 13. To prevent this, we must provide a sufficient supply of air for each, without drawing upon the other.

If a chimney be colder than the air of the room with which it communicates, a current may be established downwards, and we may have not only the smell of soot, but the smoke of a neighbouring flue, in the room. In the Annales d'Hygiène, it is recorded that two individuals were found dead in their beds, in a room in which no charcoal had been burnt, and which had an open chimney. After careful investigation, it was ascertained that a slow charcoal or coke fire had been kept in the next room, and, partly by its overpowering influence, and partly by the coldness of the flue, the carbonic acid and carbonic oxide had descended into the room in sufficient quantity to destroy life.

If the glass tube over the candle be narrowed at its lower extremity, the velocity of smoke through the opening will be greatly increased, but the total amount of air escaping will be diminished. If the tube be inverted, that the narrow part may be at the top, the heated air will move more rapidly as it escapes into the atmos-

phere, but the total quantity will be diminished. Hence we see the advantage of contracting, to a certain extent, the throat and top of a chimney, that the draught in the fireplace may be increased, and that the smoke may be discharged into the air with more force, and be less likely to be driven down by slight changes in the direction of the wind ; but, as every alteration in diameter diminishes the total amount escaping, these alterations should be avoided as much as possible.

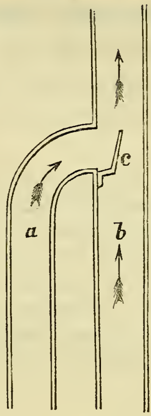
Fig. 17.



If two currents of air, in the two tubes, *a* and *b*, fig. 17, having different velocities, enter another tube, *c*, at right angles, the one having the greater velocity will diminish that of the less, according to its excess. If the velocities be precisely similar, no change of velocity will take place in either ; they will both be directed upward. The best mode of obviating the ill effects of such counter currents is represented in fig. 17, in which the dotted line, *d*, represents a division placed perpendicularly between the two currents, giving them both the same direction.

It has been observed that when a current of heated air enters a vertical chimney horizontally, as in fig. 18,

Fig 18.



it not only materially checks the current in the latter, but, if the former is very rapid, it may even destroy that in the vertical chimney as effectually as a valve.

The flue from a soda furnace entered horizontally a large chimney, fifty feet in height, having a transverse section of about six square feet ; it was observed that when the fire was first lighted the draught was sufficient, and increased as the flue became hotter, but ceased when another furnace was put in operation, the current from which was very rapid, and entered opposite to it. The difficulty was obviated by giving the rapid current a vertical direction as it entered the chimney.

In such cases, the inconvenience of these opposing currents may be obviated by placing a plate of iron in the

upright flue, as at *c*, fig. 18, which shall give the smoke in *a* a movement in the same direction as that in *b*.

In all cases of flues entering a chimney, they should be so arranged that the smoke shall assume a direction approaching that of the axis of the chimney into which they enter.

CHAPTER IX.

OF THE CURRENTS PRODUCED IN ROOMS BY HEAT, AND OF THE PRINCIPLES OF VENTILATION.

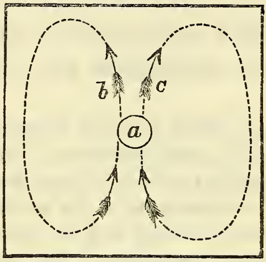
The Influence of cold Walls and cold Windows. — Double Windows. — Materials for double Windows. — Great Saving of Heat and Increase of Comfort by them. — Count Rumford's Remarks on double Windows. — Movements of Air in Apartments communicating by one or more Openings with the external Air. — Air-tight Stoves. — Spontaneous Ventilation. — Plenum Ventilation. — Vacuum Ventilation. — Mixed Ventilation. — Illustrations of Ventilation. — Dr. Reid's System of ventilating the British House of Commons.

In the preceding chapter we have endeavoured to point out the movements of heated air in tubes of a limited diameter, with a view to explaining the action of chimneys. When the heated body is inclosed in a room, certain movements are induced in the air, differing from these, which require attention. Other currents, also, intimately connected with the practice of ventilation, are induced by cold bodies, such as windows and cold walls. A third and still different class of motions arises when heated air is introduced into apartments having one or more openings for its admission and escape.

A heated cannon-ball suspended in a room, as at *a*, fig. 19, heats the air in contact with it, and currents are produced upward and outward, in the direction of the

arrows, *b* and *c*; and a corresponding inverse movement is established from all sides of the room, near the floor, inward and upward towards the ball, as represented by the lower arrows.

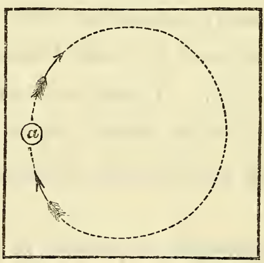
Fig. 19.



If the cannon-ball be colder than the surrounding air, the currents are in every respect the reverse, being directed inward and downward near the ceiling, and downward and outward near the floor.

These currents invariably take place in a still air, whatever be the heating and cooling bodies, whether a number of persons, stoves, or windows, or the cold walls of the room.

Fig. 20.

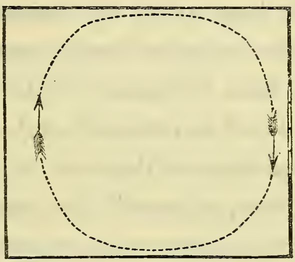


If the hot ball be removed to one side of the room, as in fig. 20, an upward current will be produced along

that side of the room near which it is placed, and downward and toward the ball along the opposite wall and floor.

When a cold window makes a part of one of the walls, a constant current of cold air descends along it, which is often mistaken for that which enters the window from without; but it will exist without that, and

Fig. 21.



cannot be prevented by closely fitted sashes, or any care in calking their crevices. The unpleasant effect of this fall of air from a number of large windows, as in churches, and their great influence in lowering the temperature of the room, are much greater than is usually supposed, especially in buildings heated by warmed air, where the walls do not feel the influence of radiated heat. In our New England climate, where the temperature not unfrequently approaches zero, and is often below the freezing point, there would be a vast saving of heat, if our churches, court-rooms, and other public buildings, could be preserved from this cooling process. This can be done by means of double windows, fitting closely, and inclosing between them a quantity of air. Air,

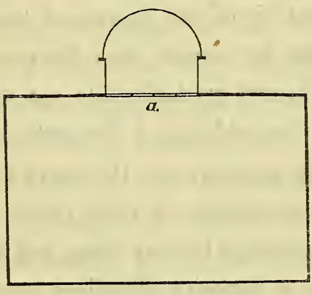
as is well known, transmits heat only by a change of position among its particles ; each particle may receive a portion of heat from a heated body, and, by coming in contact with another less heated body, communicate its heat to it, but not otherwise. One particle never communicates its heat to another particle. Hence, if glass, or any other material which transmits light, be placed at two or three inches distance from the glass, the inner sash will be kept warm, the circulation of the air between the sashes going on slowly ; consequently, less heat will escape from the room. If this same arrangement were introduced into the walls of the room, and the transmission of air between them cut off at two or three levels in each room, or even if the communication between the different stories were completely cut off at the floor and ceiling, great good would result.* In buildings in which a complete system of ventilation is established, these windows should, as suggested by Count Rumford, be kept up both summer and winter.

* Mr. Nathaniel J. Wyeth, of Cambridge, Mass., has adopted this principle in a brick ice-house which he has lately erected. The building is 198 feet long by 177 wide, and 40 feet high ; the walls are 4 feet in thickness at the bottom, and 3 feet 6 inches at the top, including within their thickness two air-spaces. A triple wall is thus formed, the inner and outer being 8 inches in thickness, and that making the division between the two air-spaces 4 inches. The air-spaces are subdivided in portions of 6 feet in length and 5 in height ; the first division being formed by bricks, and the second by planks resting on bricks projecting from the sides, and covered with dry tan. At the top and bottom of the building the air-spaces are made perfectly tight by masonry. The transmission of heat by the movement of the air is thus prevented, and the greater part of that which finds its way to the ice is by the radiation of the walls.

We say a complete system of ventilation, for, under such a system, windows would be required for the admission of light only, never for the admission of air. Double windows would, under such circumstances, in summer prevent the transmission of heat inwards, as in winter they prevent its transmission in the opposite direction. Glass is not necessary in the construction of double windows, where we require only a diffused light ; white cotton, stretched upon a suitable frame, and rendered impervious to air by linseed oil or other preparations, will answer equally well for preserving heat, and be much less expensive.*

Where the room receives light from a lantern or skylight in the ceiling, a current of cold air may be perceived descending from it towards the floor, producing the same sensations in those beneath as similar currents

Fig. 22.



in the side walls. The moisture of the air often condenses upon the glass and falls upon those below. Both these inconveniences can be effectually prevented by a

* For experiments indicating the cooling effect of glass, and the advantage of double windows, see Appendix, No. XIII.

horizontal window at the base of the lantern, as at *a*, in fig. 22.

The movements induced in the air of a room in which a difference of temperature exists between the internal and the external air, and where there is a communication between them, differ from those just considered.

When the air of an apartment having an opening in the ceiling only is colder than the external air, no motion will take place; its greater specific gravity prevents motion as completely as the specific gravity of water prevents its escape from a vessel having an opening only at its upper surface. Neither will any motion take place in an apartment having an opening in the floor, if the contained air is warmer than the external air; the greater specific gravity of the latter as effectually preventing it as water prevents the escape of air from a tumbler when inverted in it.

If the internal air of the apartment having the opening in the ceiling be warmer than the external, then the latter presses in and gradually lifts out the warmer; if the internal air be colder, and the outlet be in the floor, it also gradually escapes, and the warm air as gradually enters. The movements in these cases are very gradual unless the openings be very large, and in all cases the movements are in opposite directions on opposite sides of the opening, and there is a portion in the centre where the air is nearly stationary.

At doors and windows air enters by all the crevices near the bottom, and escapes by those near the top, if

the air of the room be warmer than the external ; and the reverse if it be colder. Windows having both sashes movable are, for this reason, very valuable for the ventilation of private rooms.

In the winter, or whenever the air is warmer in a cellar, the colder air from without will roll down through an open door, and, after removing all that already contained in the cellar, will itself become warmed and follow the same course. As the entering air in these cases comes from the surface of the ground, it may be contaminated with that escaping from a sewer, and the cellar or the whole house be filled with its odor. The effluvia from kitchens heated by the fire and steam of the ordinary operations, and aided by the entrance of air at an open door, may escape into the rooms above.

In a room having a fire, the cold air may enter at the top and bottom of a window, fall towards the floor, and move along near it to the flue, where it is discharged. In its progress it may even blow strongly upon a bed upon the floor, while all the air above, enveloping a bedstead of ordinary height, remains loaded with carbonic acid and aqueous vapour. In all ordinary rooms, the floor is swept by draughts of cold air, and is unfit for a sleeping-place, *especially if they have open fireplaces.*

If the fireplace be supplied with air from a flue opening under or near it, no air need be drawn from the room, and it is thus freed from all offensive currents from this cause. To effect this purpose perfectly, the air must enter in front of the fire, and in sufficient quan-

tity to supply all that escapes into the chimney, and all ventilation must be provided for in other ways.

In a room which has no fireplace or other sufficient outlet, and is warmed by an *air-tight stove*, as it is called, all ventilation goes on by the crevices of the doors and windows. Air enters beneath the door and at the lower crevices of the windows, flows along the floor to the stove, where, becoming heated, it rises to the ceiling, and finds its way out by the crevices at the tops of the windows ; hence, it is the freshest air which escapes, while the rest remains comparatively stagnant.

Fig. 23.

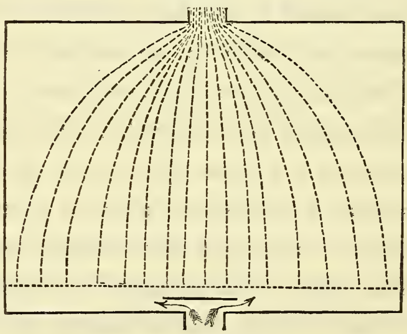


Fig. 23 represents the progress of air through an apartment by the process of *spontaneous ventilation*. The warm air receives the pressure of the colder external air through the perforated floor, by which it is diffused throughout the whole apartment, rises gradually to the opening in the ceiling, through which it escapes. If a sufficient difference of temperature existed, and the entering air were not so cold as to be uncomfortable to

those upon the floor, this would be a good arrangement; but these two requisites are hardly compatible, and another arrangement becomes necessary, — in cold weather the air must be warmed, or in warm weather the moving power must be increased.

The movement of the air has been called by Dr. Reid, according to the means by which it is brought about, the *plenum*, the *vacuum*, and the *mixed movement*. Giving here merely the general principles upon which they act, a description of the means by which these movements are kept up will be deferred to a subsequent chapter.

By *plenum movement* is meant the circulation produced by air forced in from without by the wind, or any mechanical power. Every part of the room so ventilated is subjected to a slight pressure, and air escapes through all doors, flues, and crevices; it is one of the advantages which attends this mode of ventilation, that there are no indraughts whatever, except through the proper channels. The wind-sails used for the ventilation of ships, act upon the principle of the plenum movement, the moving power being derived from the wind blowing upon the large open mouth of the air-channel. The force of the wind, acting upon a cowl turned towards it, is frequently made use of in the ventilation of buildings; and where it is combined with another in the opposite direction, with a good wind, is quite efficient. But as we cannot depend upon the constant and sufficient action of the wind, and as it has no effect in calm

weather, when we require it most, other and mechanical means must be provided. In almost all cases, air vitiated by living beings, except in the very hottest weather, is warmer than that into which it is poured. In winter it is very much warmer ; and hence, when a sufficient outlet is afforded in the ceiling, an important moving power is obtained, aiding the plenum movement ; we seldom make use of a plenum movement solely.

The *vacuum movement* takes place where we produce a difference of pressure, whether by heat applied at the bottom of a chimney, or by mechanically pumping out the air, the external atmosphere rushing in to supply its place. The reverse of the plenum movement, there is in this a pressure of air in at all windows, open doors, and flues not connected with the moving power. It is therefore a matter of great importance to the successful operation of this plan, that the windows should never be opened, and the doors as little as possible. This movement, produced by heat, is the most natural and simple, and is observed as well in the great movements on the surface of the globe as in the operations of the arts. It is the only means ordinarily employed in private houses, and by far the most common in public buildings.

The *mixed movement* is produced by a combination of the means just mentioned ; the vacuum movement being induced by a chimney, and the inward pressure, with its inconveniences, obviated by the propulsion of the requisite quantity of air. It is undoubtedly by a

nice adjustment of this mode of ventilation, that the most perfect system may be produced. When a large number of persons are crowded together in a small space, the quantity of air required for their comfort is greatly increased; and unless a corresponding increase in the exhausting power is provided, — and this is accompanied with an increased inconvenience from the pressure inwards at the doors, — mechanical means must be resorted to to make up the deficiency.

The following illustrations of the practice of ventilation are selected with a view to familiarizing the reader with the movements of air through apartments, and to give some idea of the great variety in the arrangement of the channels.

Fig. 24.

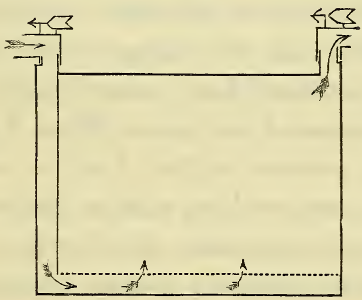
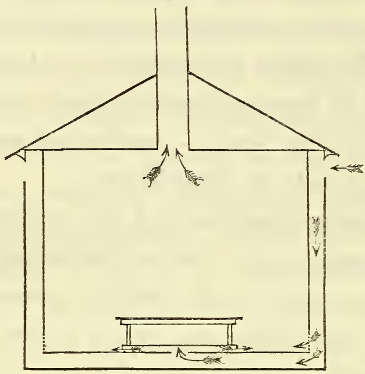


Fig. 24 represents a building furnished with cowls, or turncaps, with their vanes so arranged, that, while one shall receive the full force of the wind, the other may allow it to escape freely, and be perhaps somewhat assisted by the passage of a brisk wind over it. This is

one of the simplest modes, and, if we were always sure of sufficient velocity in the wind, would do well. It should never be depended upon alone.

Fig. 25.

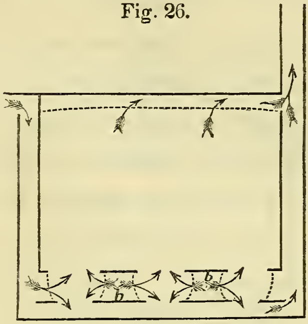


The air may enter under the coving, as in fig. 25, or beneath the windows, on either side, according to the direction of the wind, and, finding its way beneath and through the perforated floor, escape through the ventilator in the centre of the room. When it may be inconvenient to perforate the floor, it may be conducted to the base, or mop-board, by suitable channels, and admitted by a sufficient number of perforations. In large rooms, as in the wards of a hospital, additional surface might be obtained by the perforated sides of a low platform, covered by a large table, as represented in the figure.

Fig. 26 illustrates a double current, the one ascending from a certain point, and the other descending. The supply of air by this arrangement must be very

free, otherwise one moving power or the other will be checked. It must be rare that such an arrangement is required. Dr. Reid has suggested that it may be useful

Fig. 26.



in museums and galleries of art, where the articles are subject to injury from the moisture of the breath and skin, and from the dust which may be raised by a crowd of visiters. The figure shows that the first mentioned exhalations may be conducted directly upward, while the dust descends through the floor. The different fresh-air chambers, *b*, *b*, communicate with each other.

In fig. 27, the moving power is a chandelier beneath a ventilator in the ceiling ; the higher this can be carried, and the less heat lost through the sides, the greater will be its effect. If the entrance of the air be sufficiently free, — and this is the point in which we most frequently fail, — this plan will be found quite efficient. In a chapel, if the air be admitted along all the aisles, and, if circumstances permit, in the base also, the current can be so managed as to give sufficient diffusion,

without incommoding any one. When greater power is wanted, it may be aided by a fire, in a fire-proof portion of the ventilator, as at *a*.

Fig 27.

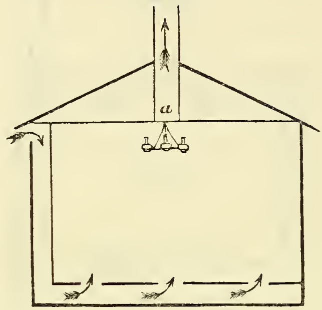
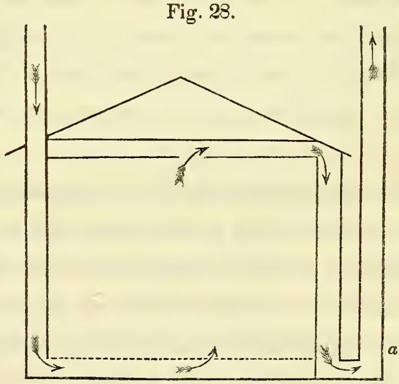


Fig. 28 shows the arrangement of flues necessary to conduct the vitiated air to the ventilating shaft on the ground, having a moving power at *a*. A larger and

Fig. 28.



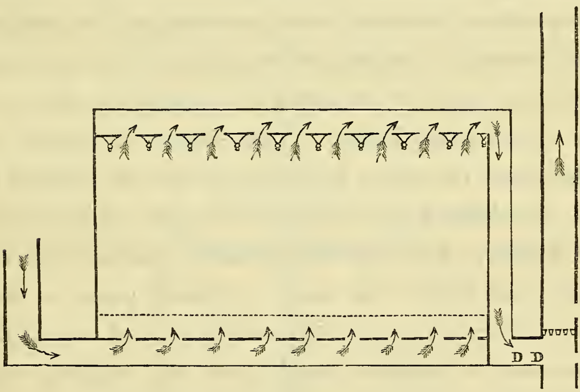
much more convenient chimney may thus be obtained, free from all danger from fire, and of easy attendance. It is true that some loss of power is experienced in

drawing down the heated air, but a slightly increased amount of fuel will replace this, and this additional expense will be counterbalanced by the facilities and security mentioned.

In all these cases, mechanical power may be substituted for the heat, being placed either at the surface of the ground, or in the ventilator above the apartment, acting either by the vacuum or plenum impulse.

The following diagram illustrates Dr. Reid's system of ventilation, recommended for the temporary House of Commons, in 1835.* "The air enters at the turret

Fig. 29.



on the left, and is heated or cooled to the required temperature by hot or cold-water pipes, or otherwise, below the floor of the house, or in any adjoining apartment. From the main trunk below, the air is either allowed to escape, diffusing itself equally below the whole of the

* See Report of Committee on Ventilation of Houses of Parliament, printed Sept. 2, 1835.

floor, or led away by separate tubes, so as to ascend with the same equal flow, whether entering by numerous small apertures in the grating along the floor, or below each individual seat along its whole extent. The row of arrows represents the apertures by which the prepared air enters the body of the house, whether along the floor, or below any single bench. Ventilating apertures placed between each pendant in the roof remove the air as it rises, which now descends, as is represented, till led into the chimney ; the furnace at the bottom, though small, being capable of working the whole of the ventilating apparatus. At D D, two doors are placed, by opening or shutting which, according to the state of the furnace, the velocity of the current from and into the house may be increased or diminished, almost to any extent, in an instant. The furnace is worked by coke alone, the doors, D, D, being shut on kindling it, and air admitted for a short time by the ash-pit doors.

"Delicate, but large thermometers, placed within the house, and also in the main ventilating pipes, as they enter and leave it, guide the attendants, and are, at the same time, a complete check upon the regularity with which every part of the operation is carried on.

"The ventilating apparatus is not used while the house is merely warming, or before it is opened for the admission of members in the morning.

"If the air be already pure within, instead of drawing in fresh air by the turret especially erected for this purpose, arrangements ought to be made for leading the

air from the descending flue to the heating chamber, doors being provided to cut off all communication with the turrets, while the circulation is maintained between the air of the house and the heating apparatus alone ; it will then be heated speedily, and the ventilating apparatus brought into play whenever the air begins to be vitiated."

When a ventilator exists in a room with a fireplace, and there is not sufficient air introduced for both, the fireplace may overcome the ventilator, and draw down vitiated air ; or the ventilator, acting with greater force, may cause the apartment to be filled with smoke from the flue. The only way of preventing such inconveniences is to furnish a sufficient supply of air for both.

Fig. 30.

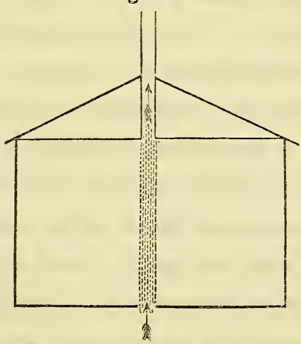


Fig. 30 represents an arrangement we observed in a public building. The heated air from a furnace, entered at the floor, and ascended in an uninterrupted column to the ceiling, which was furnished with a ventilator just over the aperture for the ingress. The apartment

could never be warmed while the ventilator was open, nor ventilated while the ingress was open; the latter furnishing all the air required by the ventilator, none was drawn from other parts of the room.

In examining the ventilating arrangements of a room, the smoke from gunpowder burnt in a spoon will be found very convenient; it need not be in sufficient quantity to heat the air materially, and yet will show the various currents in different parts of the room at the same instant. If exploded over the register in the floor for admitting air from the hot-air furnace in common use, the current will be found to rise rapidly to the ceiling, along which it will flow towards the walls, descending by these slowly, by the cold windows more rapidly, approach the register, and a part be again drawn into the ascending current. The various currents from windows and doors, if examined by this process, will be found to follow the course we have pointed out in the preceding illustrations. A fine thread of silk has been frequently used for the same purpose, but it will be found better adapted to the examination of single currents than those complications which are usually found in a room.

From a consideration of the ventilating arrangements above described, it will be seen, that, when properly constructed, the apartment resembles a piece of apparatus into which air finds its way slowly, equally, and imperceptibly, through extensively diffused orifices, and rising gradually, and filling every part, gathers itself together, increases its velocity, and escapes through its appropriate

channel, the ventilating flue. The requisites for such a movement are a sufficient supply of pure air; a diffused entrance through or near the floor of the apartment; a sufficient outlet from the highest point in the building; a moving power, constantly and steadily acting, completely under control, with such provisions at the doors, or such propelling machinery, as shall effectually prevent draughts and local currents.

CHAPTER X.

MOVING POWER FOR VENTILATION.

Moving Power for Ventilation. — Required whenever spontaneous Ventilation is insufficient. — Should not depend upon warming Apparatus, although it may be used to assist. — *Ventilating Chimney.* — Cause of Draughts in Chimney. — Mode of calculating Velocity of ascending Current. — Influence of Resistance from Imperfection of Flues. — Changes of Diameter in Chimneys. — Contraction of the Throat and Top. — Influence of Temperature on Draught. — Dimensions of Chimneys. — Ventilating Chimney of Houses of Parliament. — Construction of Chimneys. — Provision against cracking. — *Ventilating Fan.* — Exhausting Fan. — Blowing Fan. — Description of best Forms. — Velocity of Current from Fan. — Of the Fan with curved Vanes. — Practical Rules to be followed in constructing Fans. — Dimensions and Velocity. — Form of curved Vanes. — *Archimedes' Screw.* — Its Advantages. — Windmill Ventilator. — Pumps. — Comparison of practical Results of these moving Powers. — Comparative Expense of building and working them. — Moving Power to be used in new Houses of Parliament. — Comparative Advantages of Plenum and Vacuum Movements.

Whenever the difference of temperature between the air admitted to warm a room and the external air, or the diminished specific gravity of the vitiated air, does not determine a sufficient ventilating current, — or, in other words, when the *spontaneous ventilation* is not sufficient, we must resort to other means to increase it. The means usually adopted are heat in a ventilating chimney, mechanical agents, and the injection of

steam into the axis of the exit flue. Of the last it may be remarked, that, although it has been used in the ventilation of mines, and is at present the most important and successful mode of producing a draught in locomotive engines, it is hardly admissible in the ventilation of houses, on account of the noise which an intermitting jet of steam produces when escaping into a chimney ; the chimney having very much the same effect as an organ-pipe upon the vibrations of the inclosed air. Besides which, experiments indicate that steam is more efficient in the production of a current when acting through the intervention of a fan, than when used directly. Otherwise, the simplicity of the apparatus, requiring only a boiler and connecting pipes, would make it a very convenient mode of creating a current.

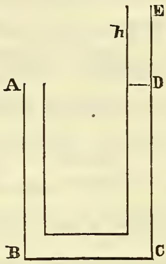
We may use for a ventilating chimney that which serves for the heating apparatus ; but to this there are several objections. We ought, in all cases, to have the heating and ventilating arrangements so far separated that we may have both under complete control ; this we cannot do, if the two are combined. The air required for the combustion of the fuel may be very properly drawn from the apartment to be ventilated ; but when the amount of ventilation is greater than that required for the fuel, it will be found more economical to have a chimney exclusively for this purpose.

In summer, and in spring and autumn, we need ventilation, especially at the two latter seasons, when either no fire or very little is wanted ; we should then be obliged

to heat the warming apparatus unnecessarily, or have a separate flue, or at least a separate fireplace connected with the same flue. Neither can we depend with certainty upon the waste heat of a kitchen or laundry-fire; they are not sufficiently constant, although they may be used so far as they go, but never without additional aid, which may be brought to act at any moment.

Fig. 31.

Fig. 32.



Ventilating Chimney.—The upward movement of air in chimneys depends upon its expansion by heat. In the section on Gases, we have shown that air expands $\frac{1}{491}$ of its bulk, at 32°, for each degree it is heated. If we have a tube, A B, fig. 31, open at both ends, the point A will sustain the pressure of the superincumbent atmosphere, while the base, B, will sustain this pressure with the addition of that contained in the tube. As fluids press in all directions, the pressure upwards, under the base, B, will also be the whole pressure of a column of the atmosphere above the level of B, upon the outside of the tube A B; consequently, if the air in A B be hotter and lighter than an equal column of external air, the pressure on B will be greater

from below upwards than from above downwards, and the air at B will begin to ascend.

In the syphon, A B C D E, fig. 32, let us suppose the leg A B filled with a fluid equal in weight to the cold air, and the leg C E, with a fluid equal in weight to the warm air ; it is evident, that, if the fluid representing warm air is lighter than the other, we must increase the length of the column, if we would have it balance the first ; let this additional column be represented by D E. Now it is shown in mechanics,* that, if the end of the tube, A, be covered tightly with the finger, and the column D E removed, on lifting the finger the fluid will spout from D with a velocity equal to that which a heavy body would have acquired in falling from E to D. This velocity, uninfluenced by friction, or any other resistance, is eight times the square root of the height E D, nearly.

To ascertain the height E D, we measure with a thermometer the temperature of the atmosphere, and of the heated air of the chimney, and multiply the height of the chimney in feet by the product of the difference in degrees between these two temperatures and the expansion for 1° ; the result is the height of the additional column required to balance the column A B. For example, let the chimney be 20 feet high, with the external air at 40°, and the temperature of the heated air 100°. 100 — 40 = 60 ; 60 multiplied by 0.002036, the expansion for 1°, = 0.1222, the expansion for 60° ;

* See Appendix, No. XIV.

20, the height of the chimney, multiplied by 0.1222 = 2.44 feet, the additional height of warm air required to balance the cold air. Eight times the square root of this height, or 12.49 feet, is the velocity per second of the air ascending the chimney.

The rate of expansion is not precisely what we have here given, for the air in this case does not expand $\frac{1}{491}$ of what it is at 40°, but at 32°.

491 parts of air at 32° have become 499 parts at 40°, and 559 parts at 100°; hence we have a proportion between the parts at 40° and 100° by which we deduce the true expansion.

Vol. at 40°.		Vol. at 100°.		Height of column.		Expanded column.
491 + 8	:	491 + 68	: :	20	:	22.405

The difference between the expansion by the first and second method is, in this example, but 0.039 of a foot, or about .08 of a foot in the velocity per second; a quantity quite inappreciable in practice.

In the preceding calculation, we have supposed that the only change which has taken place in the air of the chimney is expansion. This is not true, other changes having taken place; the oxygen has been converted into carbonic acid, which is more dense than atmospheric air, and will consequently diminish the velocity of the ascending column. To arrive at more exact results, we must multiply the quantities of nitrogen and carbonic acid in 100 parts by their respective densities, add their products together, divide their sum by 100, and divide the above result by their quotient. But as the quantity

of air converted into carbonic acid varies greatly with the management of the fire and other circumstances, and when one half of the air, as usually happens, is consumed, the quantity by which the above result is to be divided differs only .045 from unity, it may safely be neglected.

These movements are due to warm air uninfluenced by friction ; but the results of calculations in which this is neglected differ widely from facts observed in practice. Resistance has been ascertained by D'Aubuisson to be proportional to the length of the canal, to increase as the square of the velocity of the current, and to be in the inverse ratio of the diameter of the canal. To obtain a correction for friction, then, we must have regard to the height of the chimney, its diameter and the velocity of the current ; to these we must add a fourth, depending upon the nature of the materials of which the chimney is built ; for evidently a smooth surface would not offer so great a resistance as rough bricks or stones.

The formula* according to which these corrections are made is somewhat complicated, but it is easy to see, from the above facts, that chimneys should be made large, and smoothly plastered. As the same laws govern the movement of cold as of warm air, the air-trunks, whether for bringing cold air to the heating apparatus, or diffusing heated air in the apartments, should be as large, and the air move as slowly, as is consistent with the economy of heat.

---

* See Appendix, No. XV.

Variations in the diameter of the chimney must necessarily produce a change in the velocity of the air at the points at which the variations occur. Advantage is often taken of this to deliver the smoke into the air with a velocity that shall prevent its being blown down by the wind ; but if this contraction is carried beyond a certain limit, it is followed by a diminution in the draught of the chimney, which defeats the object ; the chimney-top should never be less in area than one half or one third the diameter of the chimney.

Contractions in the fireplace are also attended with an increased velocity, which augments with the diminution until it may be four or five times that due to the column of warm air. From the laws of the movement of fluids, it is seen that all sudden changes are attended with a serious loss of velocity, which does not occur if the change takes place gradually. If the change is gradual, the loss is dependent upon friction alone. Whenever, therefore, we wish to contract the fireplace, it should not suddenly take the full diameter of the chimney, but should be sloped off gradually.

In connnecting flues with a chimney, it should be borne in mind that at the bottom the pressure of the atmosphere inwards is greater than the outward pressure of the gases contained in the chimney, that at the top the pressure may be from within outwards, while at some points between the two the pressure may be precisely in equilibrium. Consequently, independently of the advantage attending a longer column of warm air above,

all flues should enter as near as possible the base of the chimney. Another point in practice, of which we have before spoken, is of importance ; two currents entering at right angles may, if of equal velocity, destroy each other, or, if of unequal velocity, the greater destroy the less. This should be prevented by giving all flues a vertical direction as they enter the chimney.

If, for any reason, we wish to introduce a flue at a point where the inward pressure is slight, it can be done by contracting the chimney suddenly just below the point, when an inward pressure will be obtained. If, on the other hand, we wish to take air from a perpendicular hot-air trunk, we can do so by suddenly contracting the main trunk just above the opening.

Although we have stated that the draught of a chimney increases in a certain proportion to the heat, still it appears from calculation that this occurs only within certain limits, beyond which there is not only no increase in the draught, but a decided diminution. This will be seen from the table, Appendix, No. XVI., extracted from M. Péclet's work on Heat, Vol. I., p. 167.

The draught at first increases very rapidly with the temperature, but gradually diminishing, it becomes constant between 480° and 570°, beyond which it diminishes, and at 1800° it is less than at 212°. The reason of this is found in the great expansion of air at a high temperature, by which its volume is so much increased, that, although the velocity may be very great, the quan-

tity, when reduced to the temperature of the atmosphere, is less than at a lower temperature.

The Dimensions of the Ventilating Chimney. — It is an important point, in the construction of a ventilating chimney, to determine the dimensions required to withdraw a given amount of air. The velocity of the air escaping will depend upon the temperature, upon the height, and the diameter of the chimney.

In all arrangements of this nature, we must be governed, in a great measure, by the expense ; increase of diameter is the least expensive, then follows height, and a constant increase of temperature is the most expensive ; besides which, we see from the table above given that this last can be carried to a certain extent only, while the two former have much greater limits.

The whole object of a ventilating chimney being to deliver a certain quantity of air, in deciding upon its dimensions, we must consider all the resistances which must be overcome by the heated column. Under ordinary circumstances, in steam-engine chimneys, and those for various purposes of the arts, the greatest resistance is offered by the grate and the combustibles upon it. Experience shows that for steam-engines a certain thickness only of the fuel is admissible, that the air may make its way through with sufficient freedom to convert all the fuel into carbonic acid. In the chimneys under consideration, it is better that all the air should not be drawn through the fire, that a portion should be admitted above it, not only for the better combustion of

smoke, but also that the temperature may be that which produces the maximum draught, about 500°, and that the resistance may be diminished by the freedom with which it enters the flue. All things considered, the most advantageous fires are those in which ten per cent. of the air is consumed, or one half of its oxygen. The thickness of the layer of coal which will answer this intention is three or four inches.

Although we may produce a great velocity in the fire by increasing the section of the chimney above it, still this cannot exceed certain limits, because the section must bear a certain relation to the height; otherwise the current of air will not fill the whole interior of the flue, and even a counter current may be drawn down from its summit.

Perhaps the best mode of determining the dimensions is to ascertain, by the formula given in the appendix, as well as we may, the resistances due to all other causes than the grate, and add one third for this. After determining the height to which the chimney shall reach (this being usually limited), and the temperature, we may then calculate the velocity in feet per second; dividing by the velocity the quantity of air to be withdrawn in feet, increased by the quantity due to each of the resistances, the quotient is the section, in feet, sought.

The ventilating chimney of the temporary Houses of Parliament is 110 feet high, circular, 12 feet diameter at the base, and 8 feet at the top, where the section is about 50 square feet. The grate is about 10 feet from

the ground. The current of air has been observed to have a velocity of 30 feet per second. The amount of coal consumed is about two tons each session of 12 or 14 hours. It has, for three weeks in succession, delivered 70,000 cubic feet of air per minute.

In all cases, it is much better to have the chimney larger and higher than is usually needed, that we may increase its power by a slight addition of fuel.

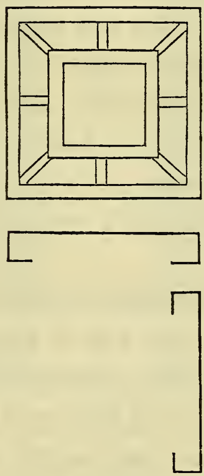
In the new Houses of Parliament, it is understood that the ventilating shaft, which is to be over the central hall, will be more than 200 feet in height, and of such a diameter as will allow of a sufficient current being produced by the heat of the vitiated air, and that from the various chimneys, the flues of which are to lead into it, without recourse to any considerable amount of additional heat, or to any mechanical moving power, besides that necessary to prevent a tendency to a vacuum in the Houses, unless they be very much crowded.

Construction of the Chimney. — The ventilating chimney should be built in that form which offers the least resistance to the current of air, and which will best withstand the effects of heat. The two most common forms are those in which the internal cross-section is circular or rectangular. With regard to the exterior, it may take any form which is most agreeable to the eye, or most in keeping with the objects around ; either a Gothic turret, or a Grecian column. The walls should be double, with an air space between, to prevent the communication of heat, and to lighten the structure.

In this country, the best material is bricks ; they should, if the chimney is large, be bound together by means of flat iron bars, turned at the ends to embrace two or more courses of bricks, and so arranged that the bars may cross each other at right angles.

A form of construction which is found to do well in practice is a square flue of the same diameter throughout, with a pyramidal exterior, strengthened as represented in fig. 33, beneath which are also represented the bars just mentioned. A chimney lately built for the

Fig. 33.



Somerville Bleaching and Calendering Company has the inner wall eight inches thick, and the flue two feet in its internal diameter ; the outer wall is also eight inches thick, and six feet by the side externally, at the base ; these walls unite at the top, which is forty inches square, externally ; its height is 76 feet, and 40,000

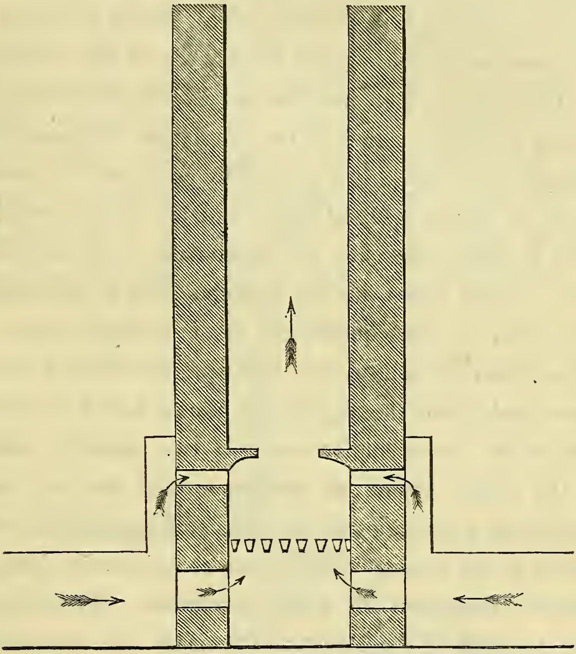
bricks were required for the construction. It is used to work the boilers which supply a steam-engine, and produce steam for carrying on the usual operations of bleaching. The size of this chimney is intended in part to prevent the communication of heat, arising from the intense fire of the engines, to the wood-work around ; consequently, it is much greater than would be required for a ventilating chimney.

The air should be admitted to the ash-pit, and above the fire ; in the latter, through small openings from a pipe so directed that the air on its entrance may be thoroughly mixed with the heated and burning gases. If more air still is to be carried through the chimney, it must enter two or three feet higher up, and so arranged that it may take a vertical direction before meeting the ascending current. The same care should be taken with that entering below the fire, if it comes from opposite sides of the ash-pit.

In fig. 34 is represented a form of chimney which will be found to work well if devoted to ventilation alone. In most cases, however, it will be better to bring all the neighbouring flues to it, both to secure for them a good draught, and to take advantage of their waste heat. If this be done, these flues may enter where it is most convenient, taking the precautions as to direction just mentioned. The air-flues and chimney should be fitted with good valves or registers. In the air-flues, those turning on an axis, the extremity of which protrudes externally and is furnished with a han-

dle, are the most convenient. If a circular plate of iron pierced with holes, is fixed against the flue, and a small pin passed through the handle, we may secure it in any

Fig. 34.



position. Upon the plate, against each hole, could be noted the number of square inches of free surface in the flue, when the handle stood over the hole. In the chimney, the usual valve is a flat plate placed at the top. This plate has an arm projecting from its upper surface, moving in a bracket, fixed to the side of the chimney near its top; a chain or rod is fastened to the arm, and descends to the ground, by which the plate is readily

moved. The great advantage of this arrangement is, that it is so far removed from the fire that it is not injured by the heat. If the heat of the fire is not very great, a more convenient valve would be that proposed for the air-flues, or a cast-iron plate, sliding in guides of the same metal, laid in the brick-work of the chimney.

The Fan. — The machine usually employed for producing a current, either in the ventilation of mines or of houses, is the fan. It is essentially composed of several vanes, or blades, inserted into a shaft, and made to revolve with it, either vertically or horizontally. By the rotation of these vanes, the air between them is put in motion, and, in consequence of the centrifugal force, is driven from the centre, and, if it were not allowed to escape freely from the tips of the vanes, would be compressed at the circumference. If two sides be added to the vanes, having an opening around the axis, and leaving the extremities of the vanes still open, the air will rush in at the central opening, and escape at the circumference, throughout the whole revolution. By adding a tube to each of these central openings, and connecting them with the rooms to be ventilated, the fan will produce, when in motion, a flow of air from the rooms proportional to its size and velocity. Fans have usually received the names of *blowing* and *exhausting* fans; blowing, if it is the circumference which is connected with the room to be ventilated, and exhausting, if it is the centre ; in the first case, the air of the room is compressed, and in the second, dilated. The only dif-

ference between these two machines being in some arrangements for preventing loss of power by leakage; the moving part of the fan is in both the same.

Various forms have been adopted in the construction of the sides of the fan, and in the arrangement of the vanes or blades. In some, the sides are united firmly to the vanes, and in others, only one side is movable, while the vanes revolve as near as possible to the other, which remains fixed. In some, the vanes are plane, arranged in the direction of radii to the axis of rotation, and in others, curved. In the latter, the fan moves in the direction of the convexity of the curve.

Fig. 35.

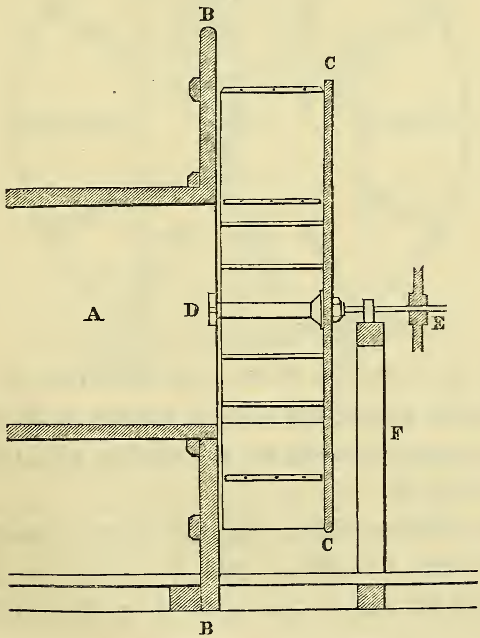


Fig. 35 represents a section of a fan with plane

vanes, the section being made in the direction of the axis. These vanes are twelve in number, usually made of sheet iron, and arranged in the direction of radii to the axis of rotation. A is the air-channel ; B B, the fixed side ; C C, the movable side, to which the vanes are attached, and which revolve with the axis D ; E, the driving pulley ; F, the standard, supporting one end of the axis, the other turning in a cross-bar attached to the fixed side.

Fig. 36.

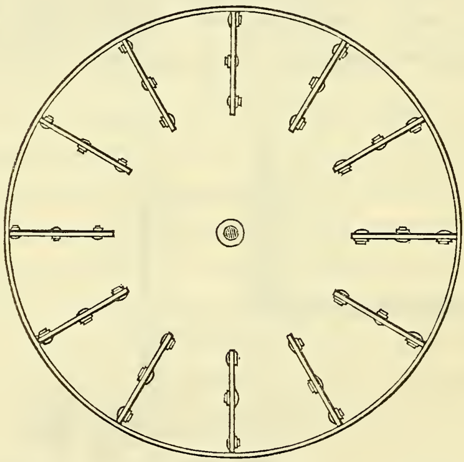
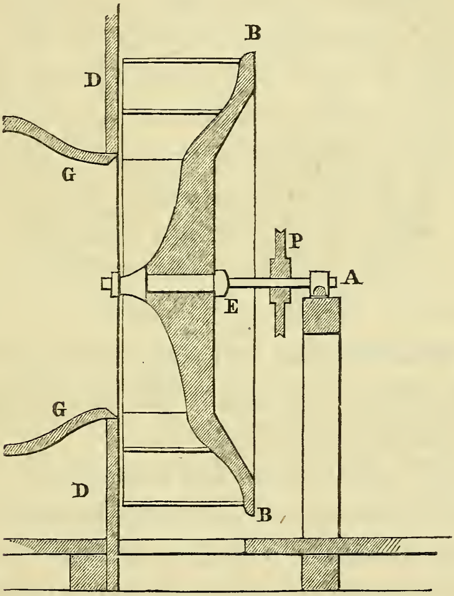


Fig. 36 is a section of the same fan, across the axis, showing the number and relative position of the vanes ; they are attached firmly to, and revolve with, the side C C, in fig. 35.

The following figure (fig. 37), from Annales des Mines, 1839, Vol. XV. p. 232, is a section, in the direction of the axis, of the fan used by M. Combe, in

the ventilation of the Belgian mines. The vanes are of sheet iron, curved, ten in number, and fixed with the axis to the movable side. The movable side is curved, as represented in the section, in such a way that the spaces between the vanes have cross-sections of equal area from the opening at the centre of the fan to its

Fig. 37.



circumference. To prevent the rotation of the air at the centre, and to force it to enter the spaces between the vanes at a determinate angle, a plate of iron is placed across the central opening, attached to the fixed plate by its two extremities, and of sufficient width to extend from one side of the fan to the other. A is the axis;

P, the driving pulley ; B B, the movable side, attached to the axis by the screw, E ; D D, the fixed side ; G G, the sides of the air-channel.

Fig. 38.

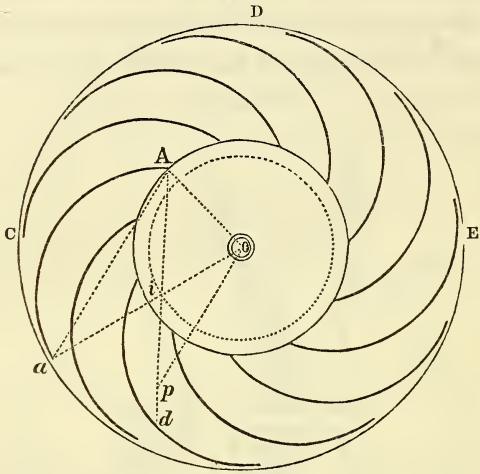


Fig. 38 is a section of the fan, with curved vanes, giving the form of the vanes. The fan is supposed to move in the direction C D E.

In both these fans the axis is horizontal ; it may, however, be vertical, and such an arrangement affords a better opportunity for making the movable parts tight, and preventing leakage of air. A circular trough, three inches in width, and six inches in depth, may be placed on the horizontal top of the air-channel, into which a short cylinder, attached to the side of the fan, descends nearly to the bottom. This cylinder has the same centre as the circular trough and the fan. The trough is half filled with water, and all communication is thus effectually cut off, without producing friction.

To convert these fans, which are here represented as exhausting, into blowing fans, they must be surrounded with a case. When thus used, the sides of the fan will be formed by the sides of the case, and the moving part will consist only of the axis and its radii carrying the vanes. It is not necessary that the sides of the case should be in close contact with the vanes, but only that their tips traverse as near the sides of the case as they can well do without touching. This case is usually placed nearly in contact with the ends of the vanes, except at a certain portion of the circumference, to which the air-channel communicating with the apartment into which the air is to be thrown is attached. In some forms, the case is made of a larger diameter than the circle described by the tips of the vanes, and these last are eccentric with regard to it, being placed nearer that portion of the case from which the air-channel commences. This is an improvement over the first, inasmuch as it allows the air to enter the spaces between the vanes, through a larger part of the revolution. A better arrangement* is to place the sides of the case at least two feet from the circumference of the fan, and to attach the air-channel to any point of it that may

* It will be seen that the ventilating fan is regarded as acting differently from that used in foundries, where velocity and pressure are wanted; consequently, no advantage can be derived from giving the air any absolute velocity, by impelling it forward into the air-channel. The eccentric fan may derive some advantage from the impelling power of the tips of the vanes, but even then a still greater advantage arises from the constant flow of air which is allowed by the constantly increasing space.

be most convenient. But even with this arrangement, the air in the space surrounding the vanes is somewhat compressed, and offers a certain resistance to that entering it from the fan; hence, it is generally found that blowing fans act less efficiently than those which exhaust.

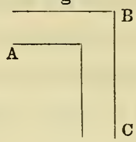
By applying to the fan the theory of the centrifugal pump, it can be shown that the air will escape through the canals formed between the vanes, with a velocity equal to that of the rotation of the tips of the vanes, if no resistance be experienced in drawing the air into the machine, or in pushing it into the surrounding medium, and if there is no resistance from friction in the canals themselves.* Practically, resistance is experienced under each of these three forms, and the result is modified by it. We see, also, that the air, at the same time that it moves outward from the centre, is carried forward by the rotation of the vanes, and the direction with which it finally leaves the fan is the resultant of these two motions. It is not necessary in fans for ventilating purposes that the air should be thrown forward, although it may be in those intended to supply a blast for a furnace, and, to avoid it, the vanes have been made curved; the curve, which is a part of a circle, is so constructed, that, as the air moves outward, the space between the vanes curves backward, and allows it finally to escape directly outward, the tips of the vanes being nearly tangents to the outer moving circumference.

Another advantage has been supposed to belong to

* See Appendix, No. XVII.

the curved vanes. If we have a curved tube, A B C, as in fig. 39, moving around the point C, in the direc-

Fig. 39.



tion A B, we see, that, although the part B strikes the air as it revolves, and occasions some resistance, the air in front of the end A is dilated, and this dilatation tends to draw the air through the tube in the same direction as the centrifugal force, and with a certain relation to it. This influence must always exist, for the air never can flow so rapidly into the partial vacuum formed by the revolving tube, that a portion shall not be drawn through it. The same conditions exist in the spaces between the vanes of the fan, any two contiguous vanes forming curved tubes like that above described. A portion of the moving power may thus be saved, although the increased friction due to the greater length of the vanes must considerably reduce it.*

If the sides of the fan with vanes in the direction of the radii are parallel, the spaces between them increase in area as they leave the centre, which does not take place with the curved vanes. The consequence of this

* M. Péclet, Traité de la Chaleur, p. 223, remarks that the fan with curved vanes, by M. Combe, has never been constructed on a large scale, and the results of his calculus have not been tested by experiment. M. Péclet sees no peculiar advantages over those with plane vanes. For an elaborate paper by M. Combe, containing the mode of construction of his fans, and the mathematical investigation connected with them, see Annales des Mines, Tom. XVI., p. 280.

must be that the moving power is less, in proportion to the velocity of the air in the air-channels, in the former than in the latter; for it is well known that less air will escape, under the same pressure, from a tube having the same diameter throughout, than from a tube the termination of which is a cone enlarging so gradually that the air entirely fills it.

The dimensions of the tubes formed between the vanes should be such that the air may have the same velocity throughout its whole section, and escape freely from their extremities. If the vanes are too short, air will be drawn from the circumference inward; if too long, the only inconvenience will be the increased friction due to the increased length; but, as the resistance is slight, compared with the other resistances to be overcome, it is better to make them too long than too short. It has been proposed to make the outer circumference of the fan double the diameter of the central opening, and to have six of the vanes equal in length to the distance between the central opening and the circumference, with an intermediate vane of half the length between each, but terminating, like the first, at the circumference.

A similar arrangement has been adopted in the curved vanes; but, instead of having the whole of the shorter vanes placed at the circumference, a portion of the middle of the curve is removed, leaving portions at the two extremities, to give the proper direction to the air at its entrance and exit.

To avoid sudden changes of velocity, and a consequent loss of power, a certain relation should be established between the area of the central openings, and the space between the two sides, or depth, of the fan. If the fan has a central opening in each of its sides, the distance of these sides from each other should be equal to the radius of the opening ; and if it has but one opening, this distance should be but half as great. By this rule, the surface of the cylinder by which the air enters between the vanes is equal to the area of the openings.

In determining the dimensions of a ventilating fan, we should bear in mind that it is quantity, rather than velocity, that is required. Large masses of air should be put in motion with a moderate velocity, and with but slight compression of the air which is thrown into the atmosphere by a blowing fan, or dilatation of that in the apartment, if it acts by exhaustion. If the apparatus is small, we must give both the air and the fan a much greater velocity, to produce the same effect. With increased velocity, there is increased friction of the axis, more slipping of the bands on the pulleys which are generally used to communicate motion, and more force required in bending the bands. These alone, when the number of revolutions is 1000 or 1500 per minute, are estimated to consume about one fourth of the moving power. Although the volume of air displaced increases proportionally to the angular velocity of the vanes, the moving power (even were there no friction) required to produce the rotation increases as the cube of this

volume; for, it will be observed, double the volume put in motion requires a double expenditure of power, which must be again doubled to produce a corresponding increase of velocity. Velocity in ventilation is not required; consequently, that portion of the power expended in producing it must be considered as wasted. Large fans for ventilation are much the most economical in every respect.

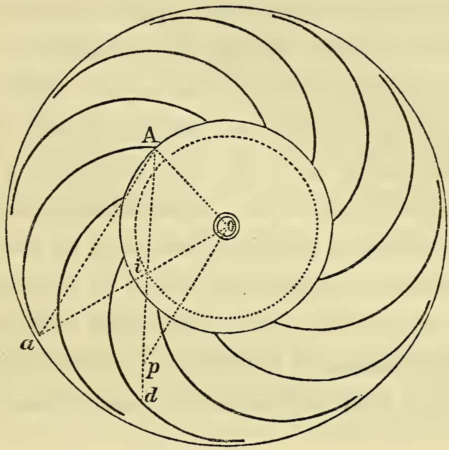
M. Péclet recommends that the central openings should have an area equal to the sections of the air-channels; but Dr. Reid goes still further; some of his fans for ventilating large public buildings have been made from ten to twenty feet in diameter. These are moved with a very moderate velocity, compared with those used in foundries, which make from six hundred to a thousand turns per minute.

The radius of the central openings for fans with curved vanes should be about half that of the exterior circumference of the fan. The vanes are arcs of circles, which cut the circumference of the central opening at 45°, and are tangents to the exterior circumferences. The number of the vanes should be from ten to twelve. Like the plane vanes, they may revolve within a case, or attached to one or both sides. The sides may be made of wood, with the sheet-iron vanes inserted in grooves cut upon the inside, if they do not revolve independently of them.

To draw the curve for the vanes, describe two concentric circles (fig. 40), the larger marking the external

circumference of the fan, and the other the central opening. From any point A, in the circumference of

Fig. 40.



the central opening, draw the radius A O; let the line A d be drawn, forming an angle of 45° with A O; set off A p on the line A d, equal to the radius of the fan; join O p, and draw A a parallel to A p; then join a O, and the point of intersection, i, of the two lines A a and a O will be the centre of the arc of a circle, touching the external circumference at a, and cutting the central opening at the point A, at an angle of 45°. With the radius O i, describe a circle, and upon it set off the centres of the respective vanes.

Archimedes' Screw. This machine consists of a single turn of a broad plate of iron surrounding a shaft, like the thread of a common screw, or of two threads arising from opposite extremities of the diameter of the

axis, and making a whole or a half turn. This screw is surrounded by a metallic cylinder, one end of which communicates with the apartment to be ventilated, and the other with the atmosphere. Each revolution of the screw tends to draw through the cylinder the air contained beween the threads of the screw. But the friction of the air is found to diminish greatly its useful effect, and, so far as it has been employed, it has not been found to equal the fan. It offers some advantages, from the ease with which the movement of the air may be reversed by reversing the action of the screw. It may also be placed in the air-channel itself, requiring but a slight increase in its diameter, which might give it a preference over the fan, where loss of room was an object.

Several other mechanical means of producing movement in the air have been used ; among these may be mentioned the windmill ventilator, and pumps. The first instrument is constructed with vanes like a windmill, but with a much greater number ; it resembles, as usually arranged, a fan window-blind, the axis upon which it turns passing through its centre, and the vanes answering to the slats of the blind. The windmill is turned by the force of the wind passing by and pressing upon the oblique vanes ; the ventilator, being turned in a still air, strikes against, and draws the air through it, having precisely the reverse action of the windmill. This ventilator is also surrounded by a cylinder, and may be placed, like the Archimedes' screw, in the air-

channel, with but little, if any, increase of diameter. The pumps are sometimes worked by means of pistons, and at other times, by cylinders closed at the top, with the exception of a valve, and open at the bottom, like common gasometers. The cylinder is alternately raised and depressed in a vessel of water, through a pipe in the centre of which the air to be removed enters the cylinder as it rises ; in its descent, the valve on the top of the pipe closes, and the air escapes through the other in the top of the cylinder into the atmosphere. This machine works without friction, but acts only by exhaustion. It is used in mines.

In adopting a moving power for ventilation, regard will be had to the peculiar circumstances under which the apartments may be placed, to economy in fuel and attendance, and to efficiency.

The following results obtained by M. Glepin, an engineer of the Belgian mines, exhibit the relative economy of the different modes of ventilation experimented upon.*

Ventilating Chimneys. — In most of the experiments with chimneys, the volume and temperature of the escaping air were ascertained, as well as the dilatation produced by the draught of the chimney ; and the effect of the fuel consumed was compared with that produced by machines consuming the same quantity of fuel in the same time.

One of these chimneys was 137.5 feet in height, and 4 feet by the side. The volume of air escap-

* Péclet, Traité de la Chaleur, Tom. II., p. 475.

ing per second, at the temperature of 165° F., was 66.5 cubic feet, weighing 4.2 lbs. The loss of heat by cooling was 38 per cent. 1570 lbs. of coal, of an inferior quality, were consumed daily. The dilatation produced by the draught was .47 of an inch in water, or 30 feet in air, at 37.5° F., and the work was equal to 4.2 lbs. $\times$ 30 $=$ 127 feet; and as a horse-power is estimated at 32,000 lbs. raised 1 foot in 1 minute, or 1 lb. raised 533 feet in 1 second, 1 lb. raised 127 feet is 0.238 of a horse-power. Admitting that a horse-power requires the consumption of 15.5 pounds of this coal per hour, and as the consumption in this time was $\frac{1570}{24} = 65.42$, $\frac{65.42}{15.5} = 4.22$ horse-power, the effect produced by the chimney is equal to $\frac{0.238}{4.22} = 0.056$ of the effect that the fuel would have produced if consumed in working a steam-engine.

Two chimneys, of which one was 84 feet high, with a section of 15.6 square feet, and the other 99 feet high, and 17.36 square feet in its cross-section, gave the same results. In the great ventilating shafts of mines 700 feet in depth, it was found, however, that the effect of the fuel consumed greatly exceeded the power of a fan worked by a steam-engine consuming the same amount of fuel.

Pumps. — These are wooden cylinders fitted with pistons, having valves opening upwards; the bottom of the cylinder, which is also furnished with a valve, communicates with an air-channel. They are put in motion by a steam-engine, and their useful effect was found to be from 36 to 40 per cent. of the power of the fuel as

above estimated. M. Combe found the effect 20 per cent. in one case, and 25 in another.*

Archimedes' Screw. — The power of this machine, when driven by a steam-engine acting on the axis by means of a pulley, was estimated to be between 31 and 25 per cent.

Centrifugal Fans, with plane vanes, and but four in number, gave a result of 20 per cent., and those of M. Combe, 38 per cent.

Injection of Steam. — Steam was thrown into an upright shaft, through six tubes of wrought iron, 4 feet long, and 17 inches in diameter, each of which received a jet at its lower extremity. Useful effect only 5 per cent. A jet under pressure of 2.75 atmospheres in a chimney 130 feet high, and 46 inches square, gave 6.7 per cent.

Dr. Ure has estimated that the power of the fan, measured by the exhaustion produced, is thirty-eight times that of the ventilating chimney consuming the same amount of fuel.† But we think he must have overrated its power, although there can be no question, that, as regards fuel, it is much more efficient than the chimney. His experiments were not made upon the ascensional power of the gases arising immediately from the burning fuel into the chimney, but after they had passed under the wort-coppers of a brewery, or the boilers of a steam-engine ; consequently, their temperature did not

* Annales des Mines, Tom. VI., p. 209.
† Mechanics' Magazine, Vol. XXVII., p. 22.

probably exceed 220° or 230° F., even at their entrance into the chimney-shaft; while the temperature of these gases, arising directly from the burning fuel, would not be much under 800°.

In the experiments of M. Glepin, above mentioned, it must be observed that the power lost in the engines required to put the different machines in motion has not been regarded; consequently, their actual working power cannot be considered as precisely ascertained; the error cannot, however, be sufficient to affect materially the question of relative economy of fuel.

In point of economy of fuel, then, we find the curved-vane fan takes precedence. But a fan requires steam-power, and, if it is to be kept in constant motion, as would be necessary in a hospital, will require two engines to provide for accidents and repairs. A steam-engine is a complicated machine, and liable to get out of order, and, except in large cities, where the requisite mechanical skill can be easily commanded, cannot be trusted to. In buildings for legislative assemblies, which are in session but a part of the day, time can be obtained for repairs. In hospitals, an engine could be used for other purposes besides ventilation, — pumping water, driving a washing-machine, &c., — work which makes up no small portion of the annual expenditure of large institutions of this kind. The chimney can be used but for one purpose. The first cost of the engine and fan, and of the chimney, could not be very different. A very strong recommendation of the chimney is its perma-

nency ; if well built, it will remain for years, requiring no repair except about the grate and fireplace, and no other attention than supplying it with fuel. Its simplicity, also, its freedom from all machinery, is another advantage. Simplicity in the moving power is exceedingly important ; the more readily it can be managed by an attentive person, the more certain are we of securing a steady and efficient movement. The constancy of its operation is a strong point in its favor. Its effect does not cease immediately when the fire is extinguished ; the materials of which it is composed retain, and gradually communicate to the air passing through it, sufficient heat to keep up a considerable draught for some hours. In the ventilating chimney of the House of Commons a downward draught has never been observed, not even when it has contained no fire ; an upward current being maintained by the retained heat of the sun, and by other causes before alluded to. We have reason to believe that its height may be in no way offensive, since its area can be increased with a diminished elevation consistently with a good draught.

The most serious objection to this mode is the tendency to a vacuum. The chimney is an exhauster ; consequently, there is a minus pressure in all the apartments with which it communicates. The immediate effect is an inward draught from all open windows and open doors ; and if air enter by these places, less will come from the heating apparatus, and a constant blowing upon all those situated near them will be expe-

rienced. There will be a tendency to the introduction of air from between the walls, and from all closets which have no exit tubes connecting with the chimney. All open fireplaces in rooms under the influence of the chimney must be dispensed with, unless their flues are connected with it; and this would often require a length of horizontal flue, which, with any fuel depositing soot, would become foul; even if anthracite coal or coke were used, still the flue would be open to the objection of a liability to crack, and of thus becoming a source of danger. Glazed fireplaces could be used, each supplied with its own flue and tube for air; but there are many objections to these, apart from the trouble of being obliged to remove the glazing when the fire is to be made or renewed.

In crowded apartments, it is found impracticable to create a sufficient ventilation by the chimney, without increasing many of these objections to such a degree as prevents its adoption. In the Houses of Parliament, the plenum impulse by mechanical means is always resorted to when a greater amount of air than usual is required, and, under ordinary circumstances, a part of the impulse for the new Houses is to be derived from the wind entering a cowl opening towards it, aided when necessary by a fan. But where the amount of ventilation required is moderate, and the apartments are never crowded, as in a hospital, and where it is highly important that it should be kept up without intermission through the twenty-four hours, a chimney may be found the most convenient. All the exit flues should be collected into

one or more main trunks, terminating at the base of the chimney. Some power is lost by obliging the foul air to descend, against its tendency ; but this is more than compensated by the longer column of air heated to a much greater degree in the chimney. When proper provision is made for ventilation in connection with the original plan of the building, as it should always be, a position may be selected which shall diminish the extent of the connecting flues, and greatly facilitate all the subsequent arrangements. Where the building is already constructed, and a chimney of suitable size cannot be obtained in it, one might be placed near it, and a trunk constructed under ground, connecting it with the cellar, to which all the flues may descend.

The amount of fuel required will be a serious objection in the minds of some, but it must be remembered that the whole system is a waste of fuel. The question is, How much air is to be allowed each individual in the twenty-four hours ? The less he is allowed, the greater will be the saving. Where the expense of public institutions can be diminished, it certainly ought not to be omitted ; but economy should never come in competition with health.

The amount of fuel consumed in the ventilating chimney of the Houses of Parliament is about two tons for each session of 12 or 14 hours ; during the sitting of Parliament, the fire is never allowed to be entirely out, and during the sweeping of the public rooms, is in full blast. With the fan used as a blowing engine, air is forced into the rooms, and its density is somewhat great-

er than that of the external atmosphere ; consequently, all the circumstances above enumerated are reversed ; no indraughts can take place either by the doors or windows ; on the other hand, air will be forced outwards at all these points. Fires can be used in open fireplaces without fear of descending currents. Each room may be furnished with its own exit flue, terminating in the open air, and the loss of moving force due to the heated air by forcing it to descend avoided.

It has been imagined that apartments ventilated by the plenum movement must be much more healthy than those in which the opposite motion is adopted ; and that the wind would be more active in the one than the other.* But we readily see that the opening of doors admits of only a slight difference in density ; if this difference amounted to but five tenths of an inch, and it probably does not amount even to one tenth in the barometric column (a difference which not unfrequently occurs in a few hours in the atmosphere without appreciable influence upon our health or activity), the pressure upon the doors and windows would be one sixtieth of the whole weight of the atmosphere upon each square inch, or 36 pounds to the foot, and would render them quite immovable to ordinary exertions. Any inferences drawn from phenomena observed in limited atmospheres of three times the usual density are entirely inapplicable to the practice of ventilation.

---

* Ure's Dictionary of Arts, Manufactures, and Mines, Supplement, Art. *Ventilation.*

CHAPTER XI.

QUANTITY OF AIR REQUIRED FOR VENTILATION.

Quantity not to be determined by Theory. — Estimate of Tredgold and Arnott. — Not readily determined by our own Sensations. — Injurious Effects of deficient Supply on some Lace-weavers. — Influence of a free Supply on Appetite. — Free Supply of Air prevents the Taking of Cold. — Influence of Climate. — Quantity of Air may sometimes be limited by Cost of warming it in Winter. — French Chamber of Deputies, each Member allowed sixty-four cubic Feet per Hour. — English House of Commons, sixty-four per Minute. — Amount of Air desired. — Depends upon its Temperature, Moisture, and Velocity. — Individuals differ as to required Temperature. — Influenced by Climate, Age, Food, and previous Temperature. — Temperature of the Walls of the Room has an important Bearing. — Temperature of Air at the Points of Admission. — Importance of Moisture. — Its Effects on Disease. — Jeffreys' Respirator. — Objections to its Use. — The Sirocco. — The Harmattan. — Hospital for Invalids unable to remove to a southern Climate. — Best Constitution of Air as regards Moisture. — Motion of the Air. — Its healthful Influence. — Limits to the Reduction of Temperature which can be borne. — Partial Currents in the Air. — Proper Velocity of Air entering an Apartment determined. — Direction of the ventilating Current. — Upward Movement most natural and most easily induced. — Downward Movement may be produced. — Objections to downward Movement.

This is one of the most important of the questions arising in the practice of ventilation. We have no means of arriving at any trustworthy result by theory; for the inquiry is not merely, what amount of air is required to distend the lungs at each inspiration, or to sus-

tain life, but what will preserve a full and vigorous state of all the organs of the body. Tredgold, taking into consideration the effect of pulmonary and cutaneous exhalations, recommends four cubic feet per minute. An engineer, in the Theory and Practice of Warming and Ventilating, plainly intimates that this is more than will be required ; and Dr. Arnott limits us to two or three. These are theoretical results, and in one point of view may have some value ; they may indicate what the human frame will tolerate without immediate and marked complaint, but they certainly have no value as guiding us in ascertaining the amount of air required for systematic ventilation.

Neither are our own sensations always to be taken as measures of the purity of the air in which we live. We may have been so long accustomed to a low standard, that we are not aware of the importance of its improvement ; the evils we suffer are attributed to other and very different causes. Dr. Arnott relates the case of some lace-makers in Buckinghamshire, who, to the number of twenty or thirty, assembled in a small room in winter and kept themselves warm by their breaths, that they might save fuel. The odor of the room, although unperceived by themselves, soon became to a stranger exceedingly offensive. They became pale, their health was broken, and some of them died. Although the cause of these results was so obvious to a well informed observer, it was difficult to convince them of their folly.*

* Arnott on Warming and Ventilating, p. 57.

The influence of fresh air in increasing the appetite is well illustrated by the following fact from the Philosophy of Manufactures, p. 380. In a weaving-mill near Manchester, where the ventilation was bad, the proprietor caused a fan to be mounted. The consequence soon became apparent in a curious manner. The operatives, little remarkable for olfactory refinement, instead of thanking their employer for his attention to their comfort and health, made a formal complaint to him that the ventilator had increased their appetites, and therefore entitled them to a corresponding increase of wages! By stopping the fan a part of the day, the ventilation and voracity of the establishment were brought to a medium standard, and complaints ceased. The operatives' wages would but just support them; any additional demands by their stomachs could only be answered by draughts upon their backs, which were by no means in a condition to answer them.

In Edinburgh a club was provided with a dinner in a well ventilated apartment, the air being perfumed as it entered, imitating in succession the fragrance of the lavender and the orange-flower. During the dinner the members enjoyed themselves as usual; but were not a little surprised at the announcement of the provider, that they had drank three times as much wine as he had usually provided. Gentlemen of sober, quiet habits, who usually confined themselves to a couple of glasses, were not satisfied with less than half a bottle; others, who took half a bottle, now extended their potations

to a bottle and a half. In fact, the hotel-keeper was drunk dry. That gentlemen who had indulged so freely were not aware of it at the time is not wonderful ; but that they felt no unpleasant sensations the following morning, which they did not, is certainly quite so.*

A free change of air is one of the best preventives of the taking of cold, as it is called. When all the crevices are carefully closed, and the atmosphere becomes stagnant, we become susceptible to very slight changes, against which we cannot always guard. To protect ourselves from their injurious effects, experience has shown that the frequent renewal of the air is exceedingly important ; and the more we accustom ourselves to it, the less susceptible do we become. The amount of air required to produce this protection differs in different individuals ; persons vary in this respect, as they do in regard to food, clothing, and temperature. There is also undoubtedly a national difference ; although it is not improbable that those nations, as the Russians, which are often referred to as instances of the little influence of deficient ventilation on health, suffer much more than is generally supposed.† Climate influences

* Reid on Ventilation, p. 80.

† In Russia, the common people are frequently deprived of sensation by vapors arising from the following cause : — " Persons of rank in that country have double windows to their houses in winter, but those of the poorer classes are single. During frosty weather, an incrustation is formed on the inside of those windows, from a condensation of the breath, perspiration, &c., of a number of persons living together in the same room. This mephitic crust is mixed with the noxious fumes of candles, and of the stove with which the chamber

the quantity required ; generally, it increases with the increase of temperature, and this may in part explain the facts with regard to the nation just referred to. In India the doors and windows are made very large, and it is found necessary in the evening, even when the external air is the warmest, to throw them wide open. It is said by those residing in such climates, that a family neglecting this practice declines in health. The amount of air thus used is many times that required for removing perspiration and other exhalations ; it is to produce some other effect, the precise nature of which we do not as yet understand. In North America, embracing as it does several varieties of climate, the amount of air required in different sections must also vary.

But it may be asked, What is the limit of the amount of ventilation ? The answer to this question must sometimes be, that amount which can be afforded. The heating of air for this process is just so much fuel thrown away. The most economical stove is that which is placed in the room to be warmed, and the smoke of which is reduced to the temperature of the room ; if no change of air then take place, by crevices or otherwise, we have arrived at perfection in the economy of fuel. Whether it is advisable to practise such economy, or rather parsimony, for this is its nature, is quite another question. It is upon this principle of the

---

is heated. When a thaw succeeds, and the plate of ice is converted into water, a deleterious principle is disengaged, which produces effects similar to those arising from the fumes of charcoal." Thomas's Practice, p. 825.

non-renewal of the air and low temperature of the smoke, that *air-tight stoves* consume but little wood, that the odor of the rooms warmed by them, in which several people are assembled, is offensive, and their influence upon the health injurious. In New England the winter temperature is such that the expense of heating up the air to a comfortable point is a serious item, and the temptation to economize in this respect is with some not easily resisted. Generally, however, rooms in private houses have but comparatively few occupants, and the crevices in various parts and the frequent opening of the doors provide, although in an imperfect manner, for the renewal of the air. When the heating apparatus is a hot-air furnace, the ventilation in cold weather must be abundant.

Where the question regards schoolrooms and public buildings, — and it is in these that ventilating arrangements become most important, — the answer must be widely different. Towns are just as much bound to supply children in schools with an abundance of fresh air, as with teachers. Indeed, there are stronger reasons for the former than the latter. It should be remembered that amends for a neglected education may be in some measure made in after life, but not so with injured health. Generally, we should inquire, not on how small a sum we can warm our rooms, but how much we can afford to spend in warming pure and invigorating air, and introducing it freely into our houses.

Experiments have been made which will allow of an

approximation under given circumstances. In the valuable Researches of Le Blanc, the quantity and quality of the air in public and private buildings was carefully ascertained. In the French Chamber of Deputies, sixty-four cubic feet per hour of fresh air were allowed each individual, and of 10,000 parts escaping by the ventilator, 25 were carbonic acid gas. We shall the more readily appreciate the amount of deterioration, if we call to mind that the quantity of this gas ordinarily present in the atmosphere is but $\frac{4}{10000}$. Experiments have been made in a room prepared expressly for the purpose, upon many persons, varying in number at each experiment from 3 to 234, of every variety of constitution, and in the House of Commons every day of the session for two years, and the results show that it was rare to meet with a person who was not sensible of the deterioration of the air when supplied with less than ten cubic feet per minute. In sultry weather it was always found that from twenty to sixty cubic feet were required to sustain a refreshing and agreeable atmosphere when no artificial refrigeration was employed ; and in the House of Commons, for three weeks successively, each member was supplied with sixty cubic feet per minute.

If we consider for a moment that the lungs at each expiration are expelling a fluid, four per cent. of which is a deadly poison, tending rapidly to diffuse itself in the atmosphere ; that this same poison is continually exhaling from our skins ; that these organs, too, are yielding a quantity (twenty grains per minute) of aqueous vapor,

increasing with the temperature ; we shall not be surprised, that, in an ordinarily ventilated room, we miss that refreshing influence a free and adequate supply of air alone can give.

We would not have it supposed, that, in our private houses, ten cubic feet of fresh air per minute should enter the room for each person in it. As we have just remarked, these rooms are not constantly occupied ; they sometimes contain several thousand cubic feet, besides what must unavoidably enter on opening the doors or through the various crevices about the doors and windows. All these circumstances must be taken into consideration, and they vary with each individual case. We shall recur to this subject when speaking of the ventilation of private houses. In public buildings, this estimate must not be taken without due regard to all the existing conditions. Many modifications may be required to render this quantity healthful and agreeable. The air must enter with a proper temperature and velocity, and hold in solution a certain quantity of aqueous vapor. All these conditions must be in unison ; a want of harmony in either will be followed by a derangement of the others.

TEMPERATURE.

This condition of the admitted air must depend upon several circumstances, — upon the number of persons, its velocity, and moisture. The greater number of persons, the more heat will they impart to the air in contact

with them, and the more will be imparted to the walls of the room.* In a dense crowd, air admitted slowly through the floor, at the temperature of 60°, rises to the temperature of 70° or 80° before reaching the head.

In experiments made on this subject, the temperature of air from different individuals, inclosed in a box lined with cotton, open above and below, and suspended in the air, was found to be generally 4° higher above the head than below the feet. At natural temperatures, a current constantly ascended from the person on all sides.†

Individuals differ as to temperature, as well as with regard to the quantity of air desired ; one will be pinched with cold in a temperature at which another will be but comfortable. We knew a medical gentleman, who, on entering his office, invariably threw off his coat, even when his pupils were uncomfortably cold. The same individual varies in his feelings of warmth at the same

* Experiments showing the heat given off by the human body, in a lecture-room 34 ft. 6 in. long, 23 ft. wide, and 9 ft. high. Number of persons in room, 66 to 68. External temperature, about 32°.

1st day,	9 A. M.	Thermometer,	40°
Lecture commenced,	10 "	"	44°
	10¾ "	"	57°
2d day,	9 "	"	48°
Lecture commenced,	10 "	"	51°
	10¾ "	"	64°
3d day,	9½ "	"	48°
Lecture commenced,	10¼ "	"	52°
	$10^h 50'$ "	"	62°

† Appendix, Part II., to Second Report of the Commissioners for inquiring into the State of Large Towns and Populous Districts, p. 138.

temperature. To one well supplied with food a degree of cold may be comfortable which would destroy another; a starving man is soon frozen. The kind of food used has an influence on the heat-producing power. Persons inhabiting cold climates consume more animal food, and of a fatter kind, than those of a temperate or hot climate. Age has a marked influence on the production of heat, the young child and the old man approaching in this respect. As age advances, the old man draws near the fire, because his power of producing heat is diminished; and it has been observed in hospitals for the aged, when the temperature of the dormitory in winter sinks two or three degrees below the usual point, that by this slight degree of cooling the death of the oldest and weakest, males as well as females, is brought about. They are found lying tranquilly in bed, without the slightest symptoms of disease, or the usual recognizable causes of death.*

Exercise is well known to increase ability to endure cold. A person who has been riding on horseback may complain of the heat of a room, while one who has walked slowly to it may complain of its coldness. Those from warm climates, during their first winter at the North, expose themselves, unprotected, to a degree of cold which the inhabitants will not meet. In Napo-

* Liebig. For many interesting and valuable observations and experiments on the influence of temperature, moisture, and air, in motion and at rest, on the animal economy, see "Researches on the Influence of Physical Agents on Life," by W. F. Edwards. Translated by Dr. Hodgkin and Dr. Fisher.

leon's Russian campaign, the soldiers from the mild climate of Italy endured the hardships to which they were exposed much better than those from more northern countries. Those who have been well warmed at a fire before going into the cold air bear it better than others. In both these cases, a stock of heat-producing power seems to have been laid up which lasts for a considerable time. The mental state, health and disease, will influence the temperature desired. Patients in a hospital are in different conditions as to temperature ; those confined to their beds usually requiring a less heated atmosphere than the convalescent who are able to sit up and move about.

An individual seated in a room warmed by heated air is differently situated from another in a room heated by an open fire, or any other radiating body placed in it. In the first case, the atmosphere of the room may be at 70°, or even higher, and yet be chilly. The walls have not become heated ; the individual is constantly radiating heat to them and to the cold windows, and receiving none in return except that derived from the air, which is insufficient. In the other case, the walls, the furniture, and the carpet all become warmed, and the amount of unrecompensed radiation is greatly diminished. When the windows of a room thus warmed are thrown open, and the fresh air allowed to blow through it, and again closed, the heat appears to be restored much sooner, and we feel much less uncomfortable, than in a room warmed by heated air. The individual also has the ra-

diated heat of the fire upon his clothes, draws up to it, and is really warmer there than in any other part of the room. We are not of those who believe that it is of no consequence how a room is warmed, so that it is warmed ; we believe there is that in a blazing fire to look at and feel, for the absence of which no mere warmth can compensate.

Air at the point of admission must bear a certain relation in temperature to that of the apartment to be warmed. If it be very hot, it may ascend directly to the ceiling, without imparting its heat to bodies around. In a church heated by two large hot-air stoves, delivering the air through two large openings in the floor, we have found a difference, after the heating process has been going on three hours, of more than 20° between the temperature near the ceiling and that at the floor. In some public buildings a stratum of air has been observed at the height of twenty or thirty feet from the floor with a temperature above that of boiling water, while below it has been disagreeably cold. In private houses, with the hot-air furnaces now in general use, air is usually introduced at a high temperature, that less of the air of the room may be displaced, and less heat be lost. We have already pointed out the course that air thus introduced will take. It rises directly to the ceiling, spreads out upon it, and, on reaching the walls, descends by them and the windows, more rapidly by the latter, until it reaches the floor, along which it is diffused towards the register, where a part is again drawn

into the ascending current. Hence we see that those assembling around the register, and not over it, are in the *coldest* part of the room. That this is the case we have also proved by the thermometer; while the air midway between the floor and ceiling in a moderate sized sitting-room was at 74°, that near the register was but 68°.

Even in a room heated by a stove, or any other apparatus placed within it and upon the floor, the air is found, after a time, to arrange itself in horizontal layers, the temperatures of which decrease from above downwards. In an experiment made to ascertain the different degrees of temperature existing in a room thus warmed, twenty-one feet in height, thermometers were hung, at intervals of about two feet, from the floor to the ceiling; their indications were as follows: —

Level of floor . . .	65°
2.1 ft. from floor . . .	67°
4.2 " " . . .	70°
6.3 " "	72°
8.4 " " . . .	75°
10.5 " "	80°
12.6 " " . . .	81°
14.7 " "	86°
16.8 " " . . .	90°
19 " "	94°*

We see, then, that a temperature depending upon several conditions will be required; we have reason to be-

* Annales d'Hygiène Publique, Juillet, 1844.

lieve that in private houses the air should never be allowed to remain above 70° when warmed by heated air; when heated air is used in connection with open fires, or other radiating bodies, the temperature will not often require to be above 65°. Where systematic ventilation is practised in public buildings, the temperature of the admitted air must depend principally upon the density of the crowd; in private houses it should not exceed 150°.

MOISTURE.

We have already shown, in the chapter upon the Atmosphere, that air holds in solution a variable amount of aqueous vapor, limited by the temperature. The influence of this agent upon the human system is exceedingly important. The lungs are continually exhaling moisture (see chapter on Respiration, p. 58), its quantity depending upon the hygrometric state of the atmosphere. Whatever be the condition, as to moisture, of the inspired air, it is uniformly expired very nearly saturated with aqueous vapor; and as its avidity for moisture is inversely as the quantity it contains, it is obvious that the amount removed from the lungs must also vary in the same proportion. The skin also loses moisture by the two processes of insensible perspiration and transudation, or sweating. The former of these, by which much more (nearly six times as much, under ordinary circumstances) is lost than by the latter, is greatly influenced by the hygrometric state, the motion, and rarefaction of the atmosphere. If the air be too dry, the

lining membrane of the lungs, throat, and mouth may be deprived of its necessary moisture so rapidly that an uncomfortable degree of dryness, or even inflammation, may be induced.

During cold weather, when a room is heated by means of a stove or a hot-air furnace, many persons experience a painful sensation in the chest, produced by the excessive dryness of the air consequent upon raising that possessing only the amount of moisture due to 32° to the temperature of 70°. This unpleasant feeling, which is often confounded with too great heat, is frequently relieved by placing a vessel of water upon the stove or in the furnace ; but it is rare that the quantity thus evaporated is sufficient to give the necessary amount of moisture.

Some animals may be destroyed by exposure of the skin and lungs to dry air. In some diseases these organs are dry, and it becomes necessary to prevent all evaporation, or even to add moisture to them. This can be done by generating a large quantity of steam, and diffusing it thoroughly in the air to be breathed. Late observations have led some physicians to believe that breathing an atmosphere saturated with moisture affords the greatest relief, and does more towards the cure of that terrible disease of children, *membranous croup*, than any other known means.

Mr. Julius Jeffreys infers, we believe, that, in all cases of inflammation of the organs of respiration, they are more dry than natural, and, before any cure can be

attempted, evaporation from the surface must be prevented. To effect this, he covers the mouth and nose with the respirator, an instrument composed principally of fine wires, upon which the vapor of the breath is deposited, at the same time that their temperature is raised by its warmth. The inspired air, as it traverses the wires on its way to the lungs, is thus both moistened and warmed before entering them ; the invalid carries with him an atmosphere in some degree constant in both these particulars. We have always doubted, however, whether the animal matter held in solution in the vapor, and deposited with it upon the wires, and which is again conveyed to the lungs with the inspired air, may not diminish the good effect we might otherwise obtain from this instrument ; whether the patient does not carry with him an atmosphere constantly impure, as well as moist and warm.

It is possible that a hospital might be constructed with efficient apparatus for warming and ventilating, in which an artificial atmosphere of any assignable hygrometric state could be maintained. Experiments could be tried, which might lead to important results in the treatment of diseases of the respiratory organs, and afford great relief, especially to those who are unable to obtain the advantages of a removal to a southern climate. We are not so sanguine as to suppose that all pulmonary diseases may be cured by such buildings. Tubercular disease is admitted by all to be, except in very rare cases, incurable. But decided advantage may reason-

ably be expected in inflammatory affections of the trachea and bronchia, especially if attended with frequent cough and little expectoration, even when complicated with tubercular disease ; such cases, in fact, as would be benefited by removal to a southern climate.

That the fluctuating quantity of moisture has its influence is proved by our sensations. There are times when the most healthy and vigorous are oppressed with languor, which they justly attribute to the weather, while at others they feel braced and exhilarated. Perhaps it is not too much to say, that, when the atmosphere is warm and loaded with moisture, a hundred times the amount of air that would suffice when cool and dry may be borne with pleasure. In the close and sultry weather which accompanies the former state, there must be a diminution, or even suppression, of the insensible perspiration, which cannot be discharged into an atmosphere already loaded with aqueous vapor ; while, with an atmosphere properly constituted in this respect, all the vital functions may be increased in energy so long as the transpiration continues unimpeded.

The Sirocco is invariably charged with moisture, and its effects upon the animal economy will illustrate, but in an exaggerated degree, the influence of damp, warm weather. When it blows with any strength, the difference between a moist-bulb thermometer and a dry one seldom exceeds four or five degrees ; a temperature of 86° often has a dew-point of 80°. The higher its temperature the more distressing its effects, owing to

the little evaporation it produces. This last is connected with its humidity, the principal cause of all its peculiarities, — of the oppressive heat, — of the perspiration with which the body is bathed, — of its relaxing and debilitating effects on the body, and its lowering and dispiriting effects on the mind.

The Harmattan, on the contrary, which blows from the scorching sands of Africa, is so extremely dry, that, when it lasts some time, the branches of the orange and citron-trees become dry ; the covers of books warp as if they had been before a large fire ; panels of doors, window-shutters, and furniture, crack and break. The effects of this wind upon the human body are not less remarkable ; the eyes, lips, and palate become dry and painful. From these facts, the Harmattan might be thought unhealthy ; whereas quite the contrary is observed. Its first breath cures intermittent fevers. Patients recover their strength ; remittent and epidemic fevers also disappear, as if by enchantment. Infection, even of small-pox, cannot be communicated. This disease appeared in a slave-ship, and the owner determined to inoculate those who had not taken it. All who were inoculated before the wind blew took the disease ; but, of seventy who were inoculated on the second day after it commenced, not one had the least eruption, although they went through the disorder after it ceased.*

We have already stated (chapter on Moisture), that,

* Arago on Comets, translated by Professor J. Farrar, p. 69.

during evaporation, a large amount of heat is rendered latent, at the expense of the sensible caloric of the surface whence the evaporation proceeds. Advantage has been taken of this law in cooling the ventilating current, by exposing it to a large moist surface before introducing it to the apartments. We have seen no trials of this arrangement, but, reasoning from what we know of air under such circumstances, we should doubt if its influence would be healthy or pleasant. We should fear that its amount of moisture would then be too great. A much better mode would be, using a system of pipes in which the water was kept cold by cold water, — that of a well of 50° would answer the purpose, — and allowing it to flow off slowly, while it received a steady supply. The same system which was used in winter for heating by steam or hot water could be used. The air would then deposit its water, and remain saturated at a lower temperature than that at which it would come in contact with the body. We should infer that some objections may have been found to the plan of cooling by evaporation, in the House of Commons, from the fact that the mode of cooling by cold pipes has been adopted.

The cooling effects of humid and dry air differ widely. The former, at an equal, or even superior temperature, produces a peculiar chilly feeling. It is felt to be more penetrating, and occasions paleness and shivering. It causes that state of things so well known by the invalid in New England as belonging to the east winds of spring ; it seems to diminish the heat-producing power.

A cold, dry air produces a feeling of bracing cold, which is felt merely upon the surface, and, so far from diminishing the heat-producing power or inducing paleness, increases this power, while it invigorates and reddens the skin.

Undoubtedly the best constitution of the air is that which nature affords. During the summer months, the air has gradually increased in temperature, and appropriated from rivers and other sources that amount of vapor which is required. In our houses, we should imitate the same course ; and, in heating air from below 32° to 70°, provide a sufficient supply of water, if not for health, at least for the preservation of our wood-work and furniture.

From the meteorological observations made at Washington, it would appear, that, during the months of June, July, August, and September, the dew-point is, on an average, at least 11° below the temperature of the air, and sometimes more than 20° below, between the hours of 9 A. M. and 3 P. M. If we assume the air of Washington to contain the usual amount of vapor, we may conclude that the dew-point of our houses in winter should be near the dew-point of Washington for the same temperature. As the temperature of the water in our wells is about 50°, a vessel containing it should receive a deposit of moisture when brought into our rooms, if they have a temperature above 65°. It is very rare that any such deposit is seen in apartments heated by a hot-air furnace, even if a considerable quantity of water

is evaporated. As a general rule, the lower the temperature, the nearer the air should be to saturation, or, in other words, the higher the dew-point.*

MOTION OF AIR.

The influence of air in motion in apartments deserves more attention than it usually receives. When the temperature and hygrometric condition of the atmosphere bear a proper relation to each other, and the air is moving gently, that feeling of comfort is experienced which reminds us of the free and flowing breezes of an open

* The following minutes are taken from the Meteorological Observations made at Washington, under the direction of Lieutenant J. M. Gilliss. They give the average temperature, the average dew-point, and the difference between them, from 9 A. M. to 3 P. M., for the months of June, July, August, and September, for four successive years.

1838.	Average Temperature from 9 A. M. to 3 P. M.	Average Dew-point from 9 A. M. to 3 P. M.	Difference.
July	85.53	71.38	14.15
August	83.00	63.32	19.68
Sept.	73.51	58.50	15.01
1839.			
June	71.85	60.03	11.82
July	78.07	64.74	13.33
August	73.71	66.21	7.50
Sept.	68.57	58.83	9.74
1840.			
June	74.08	66.55	7.53
July	77.80	71.66	6.14
August	77.37	73.85	3.52
Sept.	67.14	60.56	6.58
1841.			
June	80.24	68.06	12.18
July	80.34	66.49	13.85

country. It has been observed that persons of delicate lungs experience a feeling of closeness and oppression in small apartments, which immediately decreases on going into a large room, or into the open air. It has been apprehended that this difference is not due solely to any greater purity of the air in these larger spaces, that it may take place too soon to arise from this cause, but rather to a want of that salutary agitation which promotes a free dilatation of the chest.

The influence of motion in air of a low temperature is well known. The human body is parting with its heat in three ways, — by radiation, by conduction, consequent upon contact of the air, and by evaporation. Although radiation is influenced by the air through which it passes, a portion of the heat being lost, this loss is in no way increased by the motion of the air. By conduction, the body loses in proportion to the number of particles of air brought in contact with it; besides which, air is driven through the clothing by a wind and displaces that which was entangled in its pores and had been warmed. Voyagers to the Arctic regions inform us, that, while walking, they bore a temperature at zero, in a calm atmosphere, without inconvenience, and that a calm with the thermometer at —51° was no more troublesome than a breeze at zero. The conductors of railroad cars, when the cars are in motion, are glad of the protection of their coats and boxes, even when the temperature, to those who are not in motion, seems but comfortable. An atmosphere at 32° which is nearly

still may have less cooling power than a current at 40° or 50°, or even any temperature below that of the body itself; indeed, a velocity may be imagined of a current, at either of these temperatures, which shall reduce the body to the same degree of heat as the surrounding medium. The amount of heat lost by evaporation increases rapidly, as we have already shown (Evaporation), with the velocity of the moving air. A moist surface hanging in an open window lost three or four times as much water as one hanging against a closed window. The reduction of temperature from this cause must also increase in the same proportion.

Very different effects are produced by a current of cold air passing over the whole surface of the body from those produced by the same current passing over a small portion only. In the first case, the temperature may be merely reduced, as in the open air, without any injurious effects. In the second, it produces febrile movements, sometimes directed to the parts exposed to the draught, and at others, to remote organs; in either case, often laying the foundation for serious or even fatal disease. This point should be particularly considered in introducing air, in summer, which has been artificially cooled; its diffusion should be very extensive, and its velocity hardly perceptible.

Warm currents, on the contrary, are not only not complained of when of a suitable temperature, but are even sought, unless their velocity is excessive.

We see, then, that, although we must have a move-

ment in the air, and, indeed, can have no ventilation without it, it should be so moderated that we may not be aware of its existence ; and that it should always be considered in connection with the other two important conditions, temperature and moisture.

We have made several trials to determine the velocity which, as a general rule, with a proper regard to other conditions, will not be found unpleasant, and give as the result about two feet per second. It is evidently no greater than that with which we should pass through still air when walking with the same velocity ; although, perhaps, some difference might arise in our sensations from the muscular motions in walking. Any one who will make the experiment of walking to and fro in his room, with a seconds-clock, will probably be surprised at the slowness of his motion and the little influence it has upon the flame of a candle.

Other agents, as electricity and pressure of the atmosphere, undoubtedly have an influence upon our feelings, and may, perhaps, require some modification in the amount of ventilation required; but our knowledge of their influence is at present so limited, that it is much safer to trust to the testimony of our senses than to any merely theoretical deductions.

DIRECTION OF THE VENTILATING CURRENT.

We have shown that the flow of air may, when under the control of an efficient moving power, take any direction that may be desired ; it may move from below up-

ward, or the reverse, or in both directions at the same time.

The essential point in all the arrangements for systematic ventilation, it should be borne in mind, is, that the same air must never twice be brought within the sphere of respiration. When once respired, it should pass immediately away by a steady and sufficient movement. This, we observe, constantly takes place in the open air, where, in this country, the atmosphere is not warmer than the breath. The expired air, rendered lighter by its heat and contained vapor, immediately rises, and before a second inspiration commences, is beyond its reach. Air which has passed the body, especially when in a crowd, is also raised in temperature, and has the same upward tendency. Vitiated air, then, tends to accumulate at the ceiling.

These facts point to the upward movement as that which is most natural and most easily produced. It may take place, in cool weather, to a considerable extent, without any additional moving power, and, in some instances, if the ascending column is sufficiently long, may be all that is necessary. It requires, in most cases, but few openings in the ceiling, through which the vitiated air may escape, if the diffusion at the floor be sufficient.

There is no impossibility, however, of producing a constant and equable downward movement, which shall also effectually prevent all respired air from being again presented to the organs of respiration. The first move-

ment of expired air is, from the mouth, horizontally, and from the nostrils, downward, before it begins to rise; consequently, a downward current may, without much difficulty, be brought to bear upon and remove it.

The ceiling is unoccupied, and its whole extent may be used for the admission of air, which may reach the lungs uncontaminated by dust or contact with the body. This is the movement which constantly arises in rooms heated by means of fireplaces, and by hot-air furnaces, if the chimneys are allowed to remain open, as they should be. The current from hot-air furnaces rises immediately to the ceiling, and a part escapes by the crevices around the tops of the doors and windows, while the remainder gradually cools and descends towards the outlet, if it is left where we have supposed, and comes within the sphere of respiration. This mode of ventilation, as thus applied, is, however, imperfect, since it violates the rule which must be considered as essential in every good system, that air which has been once respired should not be again presented to the lungs. The respired air, which at first rises and mixes with the fresh air ascending from the furnace, descends with this air, and is again breathed, but in a diluted state. This kind of downward movement is generally the only practicable mode of ventilating, and at the same time of warming, private houses.

There are, nevertheless, objections to the downward movement, which have thus far prevented its adoption, to any extent, in public buildings. It requires that the

openings for the escape of the air should be nearly as numerous and diffused as those for its admission in the ceiling. If they are few in number, those near them will be seriously incommoded, while those at a little distance may be suffering for want of air. In the upward motion, the entering air, if it is admitted with a proper velocity, preserves a course nearly perpendicular to the floor until it has passed quite above the heads of those standing or sitting upon it, and then begins to be drawn together to enter the ventilators in the ceiling. The moving power must be constant, for the downward movement; if it fails, all motion ceases at once. The lights, also, must be provided with air entirely separate from that which supplies the room, and the products of combustion must be completely removed.

By these considerations, and the results of experience, we are led to believe that the movement which will be found most satisfactory is that from below upwards. The exceptions to this rule, which arise from some peculiarities in the construction of the building or in the purposes to which it is applied, will be mentioned in the following chapters.

CHAPTER XII.

OF THE VENTILATION OF PUBLIC BUILDINGS.

The Arrangements once made are permanent, and attended with but little annual Expense. — Should be determined upon before the Construction of the Building is commenced. — Flues and their Construction. — Introduction of Air into the Apartment. — Exit-flue. — Committee-rooms to be supplied with Air moderately warmed. — Court-rooms. — Of the Ventilation of Buildings not primarily constructed with Reference to it. — British House of Commons. — Dr. Desaguliers's Plan for its Ventilation. — Sir Humphrey Davy's. — Marquis of Chabannes'. — Dr. Reid's Plan for temporary House of Commons. — New Houses of Parliament. — Ventilation of the French Chamber of Peers.

THE great question upon which ventilating arrangements usually turn is that of expense. Unquestionably, the affairs of government should be administered with a proper regard to economy, but certainly it is no proof of a man's economy that he deprives himself of that which his health and comfort demand. We believe it to be the duty of State legislatures to go to any reasonable expense in ventilating their halls. Many of those assembled in them are farmers and mechanics, all of the former, and many of the latter, accustomed to living and working in the open air; they feel the influence of a close and confined atmosphere sooner than those residing in cities or pursuing sedentary occupa-

tions. More sickness occurs among members of the legislatures from the country, during and soon after the session, than can be fairly accounted for by changes of habit and mode of living, and we cannot doubt it is in a great measure due to the impure air to which they are constantly exposed. It is a duty they owe to themselves and the public they represent, that both mind and body should be healthy and active.

The same is true of courts. Jurors are drawn from all classes; the same susceptibility exists, and is even increased, by the anxiety every conscientious man must feel in discharging, under trying circumstances, his duty to his fellow-citizens. If judges and lawyers, from habit, have become in a degree accustomed to a low standard of air, it is more than counterbalanced by their more constant exposure.

During some important trials, the crowd, both within the bar and in the space usually occupied by spectators, is very great, and demands a corresponding free flow of air. But in this country few rooms are so badly ventilated as court-rooms; indeed, most of them have no outlet whatever for foul air, other than that afforded by doors and windows. The air becomes heavy and oppressive, and extends its influence over all, — more, perhaps, over the judges, whose elevated position makes them sooner feel the effect of these poisonous emanations. We shall not attempt to point out the bearing which such a state of the atmosphere may have upon the administration of justice; it is too obvious.

After the arrangements for ventilation are once made, the constant annual expense is by no means great in proportion to the advantage obtained. If a chimney is used as a moving power, the only expense, beyond that required for warming the greater quantity of air, is the cost of fuel ; if a fan, the care and fuel of the engine which drives it ; and if a sufficiently high chimney can be erected, for by far the greater part of the time no additional expense for fuel will be incurred, the waste heat from the various fireplaces and the warming apparatus being sufficient.

In public buildings it is more important than in any others that the plan for warming and ventilating should be determined upon before the construction is commenced, quite as much so as that for lighting and entrances.

Architects seem entirely to forget that any such arrangements, beyond an ordinary fireplace, are required. It is but a short time since an advertisement appeared for proposals for warming and ventilating the new custom-house in Boston, not only after the plans were adopted, but after the building was completed. Any plan which can be devised for such a building, and which can be introduced without very considerable expense, must be far from satisfactory in its operation. The architect should design and build not only with regard to beauty and convenience, but to health and comfort also ; this he cannot do, unless he possesses a clear conception, from the beginning, of the means by which these several objects are to be accomplished.

In rooms like those under consideration, constructed for accommodating a large number of persons, the ventilating arrangements should be ample, and fully equal to the largest number the room will contain. Other buildings may require a more constant renewal of the air, but none require so great an amount. In churches, where the congregation is not excessive, and remains but little over an hour, the air they contain may be considered as a magazine to be drawn upon for a time ; but this should never be taken into consideration in apartments constantly used ; its amount is too small to be of importance.

In constructing the building, a sufficient space should be reserved for the heating apparatus in the cellar, and a room for mixing and tempering the air. From this room the air may be admitted, with proper distribution, directly into the apartment to be ventilated, if it is upon the first floor ; if it is not, flues must be provided. If the walls of the building are of brick or stone, the flues may be carried up in them, and, if the thickness will allow, be *vaulted*, or surrounded by an air-space, especially if in an outer wall ; the flue itself being built of brick, well plastered with lime or cement. As many of these flues are to be carried up together as can be done consistently with a convenient distribution of the air ; an arrangement which will be found to diminish the loss of heat and moving power. If they are to be carried up in the inner walls or partitions, they may be made of wood, and take up the whole thickness of the wall ; in some cases, space has been secured in the corners of buildings for this purpose.

To facilitate the distribution of air, the supply for the body of the room, the gallery, and the speaker's chair, should be kept distinct and controlled by separate valves, for the greater convenience of regulating both quantity and temperature.

With regard to the safety of wooden air-trunks, it is unnecessary to observe that the air is supposed to be heated by an apparatus which does not exceed in temperature that of boiling water ; consequently the air cannot attain even this point.

In all well constructed rooms of the kind we are considering, the seats rise as they recede from the chair of the presiding officer, leaving ample space between them and the floor beneath for diffusion of the air ; from this space it should be admitted into the room through holes bored in the risers of all the steps, and beneath the seats. The air will not then be injured by dust, as when rising through the floor, and its oblique direction as it escapes will contribute more perfectly to its distribution.

The exit of the air must be in the ceiling. A raised centre-piece, and, if necessary, raised rosettes surrounding the centre-piece, will afford all the space that can be wanted, unless the room presents some peculiar difficulties, without in the least disfiguring the ceiling. Where certain parts are required to have a greater amount of air, a panelled ceiling will be a good mode ; any panel may then be raised, and a stronger current produced from those places nearest it. From the ceiling a sufficient flue may be carried directly upward, especially if the

building is to be surmounted by a dome, and open into the air through the lantern. If no such exit can be obtained, or if the moving power is to be a chimney-shaft upon the ground, the vitiated air may be conveyed by a trunk, which in some cases may be used as a stair-case for the servants about the building ; care being taken, of course, to see that the doors can be kept closed, by springs or otherwise, without depending upon those who pass through them.

The galleries should be supplied with air from trunks in the walls, leading from the air-chamber below, and never depend upon that escaping from the body of the room. The air should here, also, enter from the risers of the various steps. As abundance of air is to be supplied, the windows must be kept closed in all cases, and in winter be made double, to prevent descending currents. The doors must also be kept closed as much as possible, or made double, that one may shut before the other opens. Entrance of air by any other channels than those provided will in a short time derange every thing.

Committee-rooms can be connected by a tube with the main flue, and the other ventilating arrangements modified to suit the circumstances of each apartment. In the public offices connected with legislatures in state-houses, it is probable, in most cases, separate fires will be used, having the air which is admitted to supply the fire and for ventilation only moderately warmed.

A special moving power must in all cases be pro-

vided, and it must be either a chimney-shaft or a fan. This cannot be too constantly borne in mind. It has been our endeavour to set it forth distinctly ; no effectual system of ventilation can be maintained without it. It must be strong enough to counteract all currents and slight derangements, and so contrived that it can be thrown off or on when required, like the driving-belt of a piece of machinery. We have already considered and compared these two modes. In these buildings power is wanted only a part of the time, and no difficulty would arise in driving a fan by a single steam-engine, especially if provided with a duplicate boiler. Sufficient time can always be found to make any repairs which may be required. The engine, to work economically, must be of greater power than is actually required to do the work ; less wear and tear of the engine is experienced under such circumstances, and less liability to accidents of all kinds. If the heating apparatus is to be worked by steam, it is obvious that the whole value of the fuel may be obtained by directing the waste steam of the engine into it.

If, as we have supposed, fireplaces are to be used in many of the smaller rooms, and if they are to be moderately warmed by heated air, a fan will be required to propel it. Separate exit flues may then be used wherever it is desired, and the fan may be placed at the commencement of the system, near the heating apparatus. The movement of the air will be independent of any exhausting power in the various chimney-flues ; consequent-

ly there will be no tendency to smoke ; a condition which cannot be obtained with a chimney-shaft, unless all the flues are connected with it.

Care must be taken, in selecting a place for the admission of air, that it be free from dust, from the effluvia of drains, and from smoke. It should be taken, if possible, at a considerable height from the ground, not only that many impurities may thus be escaped, but that advantage may be taken of the wind as a propelling power. In tempering the air, great advantage will be derived from having an air-channel which may connect the cold and hot-air portions, without passing through the heating apparatus. If a fan is used, it is obvious that admitting the cold air into the hot-air channel, just before it enters the fan, will insure a more equable mixing than can be otherwise obtained, and without requiring the large space above mentioned.

In all cases care should be taken that the flues are made sufficiently large, that the air may pass with as little resistance as possible. We must repeat, however, that in a cold climate, like that of New England, a very slow movement will be accompanied with such a loss of heat, that it would more than counterbalance the saving in the moving power.

In court-rooms, modifications of the foregoing plan are required. The same moving power may be used, and the flues, both for the admission of the cold air and for its outlet externally, may be similar, but usually the same amount of diffusion cannot be obtained.

Flues may be carried up in the walls, either inner or outer, if the court-room, as is usual, is on the second floor ; from these, air can readily be admitted through the risers of the platform for the bench, and through the front of the platform for the clerks. For the bar, the space beneath the semicircular tables may be raised, and air admitted through its riser.

To the galleries flues must also be carried, and a special opening in the ceiling for establishing a sufficiently strong current in that direction. For the jurors' seats and for other parts of the room, advantage must be taken of the steps upon which they are usually placed, and of the base or skirting-board, both of which will afford a tolerable amount of surface.

Where the warmed air is allowed to flow in beneath the floor, the precaution must be taken that every thing is made tight, or that proper channels are provided leading to the different points above enumerated. If this is omitted, air will probably be drawn from other parts of the building, and may even produce an atmosphere nearly as bad as that it is intended to replace.

Unfortunately, it is rare that we have to do with buildings in the process of erection, with the plans of which our designs may be interwoven. Where an old building is to be ventilated, the complications are unlimited. In some cases, walls are to be cut up for the admission of flues, and air-channels laid between floors ; while in others, we may avail ourselves of existing structures, and convert them into efficient aids.

Not unfrequently large public buildings are surmounted by a dome and lantern. If, as is usually the case, a spiral staircase leads from the floor of the dome to the lantern, the sides of the staircase may be boarded up and fitted with suitable glazed windows at convenient points for lighting it. The foul-air trunk may be laid to the bottom of the staircase, and the air ascend by it to the lantern, through which it may escape into the open atmosphere. An apparatus could be placed within the lantern, turned by the wind acting upon a vane over its centre, which would effectually prevent the entrance of wind and rain, and in no way injure the appearance of the building externally.

In introducing a flue, we may often cut into the wall a part of its thickness, leaving the remainder to project, and assume, by means of simple mouldings, the form of a pilaster ; they can be arranged symmetrically, and, far from being offensive to the eye, may be made even ornamental. In some cases, the walls may be *furred* off sufficiently to afford space for flues.

It is not to be supposed that any plan can be devised by which every building can be properly ventilated, whether primarily arranged for it or not. Generally we can obtain control over the attic sufficiently to place in it an air-trunk, fitted with a valve, into which all the flues may enter, and communicate with the external air. Where there is a cupola or dome and lantern, a coal-stove placed at the bottom of the upright air-trunk, properly secured against fire, will produce a draught va-

rying with the amount of fuel consumed and the height of the trunk. Very little difficulty can usually be experienced in getting a sufficiently large entrance for cold air. We can also obtain space for air-flues, either entirely or partly in the walls, as we have just mentioned, through which, by means of a perforated base, or through aisles and other vacant spaces, fresh air may enter the apartment. By such means we can procure a reasonable amount of ventilation ; not enough to put it upon the best footing, but enough to prevent most of the injurious effects we have pointed out.

The English House of Commons will afford an example of the application of systematic ventilation to a room not originally constructed with regard to any such arrangements. This apartment was occupied by the Lords, previously to the fire, October 16, 1834, which consumed Westminster Hall and the Houses of Parliament.

The Commons made attempts, from time to time, to improve the air of the House by various contrivances ; the first which seems to have produced any decided effect was the fireplace erected in the attic, by Dr. Desaguliers, in 1723. He found in each corner of the House a hole, which was the bottom of a truncated pyramid, six or eight feet in height, placed upon the floor of the room above, by Sir Christopher Wren, through which the vitiated air might escape. These were not found to effect the intended object ; as soon as the covers of the pyramids were removed, the cold air from

above descended upon the heads of those in the House below. To obviate this, Dr. Desaguliers "caused two closets to be built at each end of the room above the House of Commons, between two of the pyramids above mentioned, and led a trunk from these to the square cavities of iron placed around a fire-grate fixed in the closets; as soon as a fire was lighted in those grates, about twelve o'clock at noon, the air came up from the House of Commons through those heated cavities into the closets, and so went away up their chimneys."*

But this plan, however well contrived, was destined to fail. The Doctor had forgotten to obtain the approbation, or greatly underrated the influence, of no less a personage than Mrs. Smith, the housekeeper. Mrs. Smith had possession of the rooms which had been thus appropriated, and, "not liking to be disturbed, did what she could to defeat the operation of these machines, which she at last compassed by not having the fire lighted till the House had sat some time, and was very hot; for then the air in the closets, that had not been heated, went down into the House to an air rarer and less resisting, whereby the House became hotter instead of being cooled."

In 1736, Dr. Desaguliers introduced another apparatus for removing the impure air, which he termed a centrifugal or blowing wheel, and a man to turn it, whom he called a ventilator. This wheel, or fan, was seven feet

---

* Desaguliers's Experimental Philosophy, Vol. II., p. 560.

in diameter and one foot thick, and had twelve vanes ; it was surrounded by a concentric case, within which the vanes with their side-pieces revolved ; the opening at the centre was upon one side only, and eighteen inches in diameter. Until 1820, this fan was constantly used, and answered the purpose for which it was intended ; at that time it was superseded by the arrangements of the Marquis of Chabannes, who had previously been occupied in warming and ventilating Covent Garden theatre.* He constructed a large air-trunk over the body of the House, twenty feet in height, into which several branches, communicating with different parts of the ceiling, were led, and rarefaction induced in the main trunk by means of sixteen steam-cylinders. The foul air escaped from the main trunk through a cowl four feet in diameter.

The House was warmed by steam-cylinders, placed under the seats. These cylinders, which were twelve in number, were sixteen inches in diameter, and contained each thirty pipes of two inches in diameter. To these the external air was brought by a trunk branching to each, and was heated by its passage through them before being admitted into the House. This system, after a few years, was removed to give place to others.

The House of Lords was, for many years, warmed by two brick flues beneath the floor, communicating with

* For a full account, with plates of his apparatus, see the Journal of Science and the Arts, edited at the Royal Institution, Vol. V., p. 300.

two furnaces, the smoke from which passed through them on its way to the chimney. For the ventilation no provision appears to have been made. Sir Humphry Davy was requested to furnish a plan by which this object could be obtained, and in answer to this request the following letter was sent to the Earl of Liverpool.

"21 Albemarle-Street, 7th Sept., 1811.

"My Lord:—

"I am informed by a person attached to the House of Lords, that it is your Lordship's wish that I should give some more minute information respecting the plan which I submitted to the Lords Commissioners for considering the ventilation of the Upper House, in February, 1810.

"As no part of that plan has been as yet carried into execution, it will not be necessary for me again to speak of the general principle proposed to be adopted. I shall merely refer to the means which appear to me most proper for carrying it into execution.

"To convey fresh air into the House, I propose flues of single brick, connected with the flues for sending hot air through the vaults under the floor; and I propose that this fresh air should be admitted by numerous apertures in the floor of the House, and supplied to the flues by pipes of copper or plate-iron from the free atmosphere.

"The air in this case will be always fresh, and by regulating the fire may be more or less heated, according as the temperature of the room is low or high.

"To carry off the foul air, I propose two chimneys or tubes, made of copper, placed above the ventilators, and connected with wrought-iron tubes, which can be heated by a small fire, if a great draught is necessary, as in cases when the House is full.

"Should this plan be adopted, there would be no necessity for opening windows; the foul air would be carried off from above; warm air or cold air, whichever is necessary, may be supplied from below; and there would not be, as now, any stagnation of air.

"I shall subjoin a sketch which may be useful to the persons who may carry the plan into execution. I have already, I believe, made Mr. Davis, Mr. Groves' clerk, understand it, and I shall be happy to give any other assistance in my power during my short stay in town.

"I have the honor to be, &c.

HUMPHRY DAVY."

The flues above referred to were horizontal, and ran along beneath the floor of the House of Lords; they were fourteen inches wide and eighteen inches deep, and nearly one hundred feet in length. A sketch of the plan mentioned in the foregoing letter is given; it consisted of a tube of copper one foot in diameter placed over the ventilator, and connected with an iron tube of the same diameter, which passed through a fireplace; the remainder of the tube was of copper, and opened into the external air. The fireplace was in a fire-proof room in the attic.

This plan was not found so effectual as was desired, and in 1813 a committee was appointed to inquire into its defects. Mr. Lee, who made a report on the subject, attributed the inconveniences to its small size.

"I have found," says he, "on a very crowded night of business, that it was impossible, by means of the present ventilators, to draw off the heated air; the thermometer in the House has been up, on such occasions, to eighty degrees, and the windows were consequently obliged to be opened, otherwise it would have risen still higher; therefore he considered the ventilation pipe, which is only one foot in diameter, as quite inadequate to draw off the heated air from such a large room." He also ascertained, by putting his head over the ventilation-pipe, that sometimes, even when a fire was lighted, air passed down the pipe into the House; while at other times a strong current ascended through them, without the aid of fire. The great length of the flues allowed the unconsumed coal and its gaseous products to be deposited in or escape from them into the House.

Like all long horizontal flues, these were subject to cracking from heat, and finally, in 1834, while a large quantity of "tallies" and "foils" (about two cart-loads) were burning, by which a great fire was kept up for ten hours in succession, they became so hot that the wood-work near them took fire, and the two Houses of Parliament were destroyed.

The present temporary House of Commons is that part of the building formerly occupied by the Lords.

It was warmed by large flat tablets filled with hot water, placed in a room under the House, and occupying a space about four feet in height by nine feet square. After the air had been sufficiently warmed by contact with these tablets, it passed into the room above through seventy-eight apertures arranged along the middle of the floor. The dimensions of this room are eighty feet in length by forty in width, and thirty in height.

The opening for the escape of the vitiated air was in the ceiling, communicating with the external air ; and the ascensional power was determined by a cylinder heated by steam, through which it passed.

These were the arrangements for warming and ventilating the House of Commons in 1835, when the Select Committee was appointed to consider the best mode of ventilating and warming the new Houses of Parliament. The investigations of this committee resulted in a recommendation that some, if not all, of the alterations suggested by Dr. Reid should be submitted to the test of experiment during the ensuing recess of parliament.*

During the autumn of 1836, these alterations were made ; they were as follows : —

1. The area of the discharge was increased to fifty feet.

2. A chimney, which we have before described, 110 feet in height, was connected with this discharge by

* Report from the Select Committee on the Ventilation of the Houses of Parliament; with the Minutes of Evidence. *Ordered, by* the House of Commons, *to be printed,* 2 September, 1835.

means of a flue passing from the ceiling down to the ground. In the House of Lords it has since been found necessary to use machinery for the propulsion of the air, when that hall is much crowded, to aid the action of this chimney.

3. The area for the ingress was also increased, and the movement of the air from its entrance to its exit regulated as in a pneumatic machine ; the House, in this respect, being treated as a piece of apparatus.

4. The descent of cold currents upon the head was entirely stopped by an interior glass ceiling. This ceiling also had the effect of improving the House as regards the transmission of sound, by lessening its capacity, but still more by giving it a form better adapted to the attainment of this particular object.

5. The heating apparatus was augmented, and placed in a chamber where it could afford, at a moment's notice, any amount of warm air that might be required.

6. Mixing-chambers were provided, so as to allow the warm air to be mingled with any portion of cold air.

7. An equalizing-chamber was formed below the floor, that the local currents, otherwise apt to form unequal eddies, might be broken, and terminate in a uniform supply to every part of the floor. The galleries were supplied with fresh air by a separate channel, rendering them entirely independent of that ascending from the body of the House.

8. The most extreme and universal diffusion was given in the floor by piercing nearly a million of aper-

tures, and breaking the force of the air passing through them by a porous and elastic hair-cloth carpet.

9. Arrangements were made in the lobbies, by the alternate disposition of mats and Russian scrapers on the floor of the lobby, to secure the greatest possible exclusion of every source of impurity that could affect the air. These precautions to preserve the air pure were extended to the exterior of the building. An offensive drain, in what is called the Old Palace-yard, was connected with the chimney above mentioned, and a downward draught established through all its openings. A veil was suspended at a point by which all the air must pass, forty-two feet long by eighteen feet six inches deep, for the purpose of excluding visible soot. It was upon this veil that, on some evenings, 200,000 portions of visible soot were found to have been deposited.

Lest these precautions should not be found sufficient, a washing apparatus was established in the vault known as Guy Fawkes's vault, in which the air is drawn through a shower of water issuing from numerous holes in the sides of pipes arranged along the floor. Any mechanical impurities which may have passed the veil are detained by the drops of water with which the space is constantly filled from the dashing of the fountains upon the walls. After this, it is still made to pass through a second or third gauze veil. Besides retaining the impurities, this arrangement has the advantage of both cooling and moistening the air. By an arrangement special-

ly adapted to moistening the air, seventy gallons of water were evaporated at a single sitting.

Besides the heating of the air, arrangements are made in summer for cooling it, by filling with cold water the same tablets that are used in winter for warming. The cooling has been carried still farther, by means of bags of ice, suspended in such a way that the air will be drawn through them on its way to the House. Advantage is likewise taken of the cool night-air, which is drawn through the hall after the members have retired.

The quantity of air allowed to pass through the House of Commons is placed under the control of a single valve, by which the movement of the air can be arrested, or increased to the greatest amount, at a moment's notice. This valve is ten feet long by six feet wide, giving an area of sixty square feet. When the fire is burning well and the valve is open but two feet, the current is so strong that it would be difficult for a man in the air-flue to stand against it.*

The House is heated to 62° before it is opened, and maintained generally at a temperature varying between 63° and 70°, according to the velocity of the air passing through the House. Thermometers are suspended in the House, one in the north gallery, another in the east, and a third is placed behind the speaker's chair, attached to a cord by which it can be drawn down, through a tube provided for the purpose, to the attendants in the

* Report on Lighting the House, 1839, p. 43.

vaults below, noted, and immediately returned to its place, without disturbance or inconvenience.

The velocity is regulated by the numbers crowded upon a given space, the temperature of the air in warm weather, and the moisture it may contain. Experience has shown that some persons are more influenced by an excess or deficiency of moisture than by changes of temperature. In very warm weather, although the walls may be at a high temperature and the air at 75°, still, by increasing its velocity, it may be made to feel cool and pleasant.

In determining the degree of temperature at which the House shall be kept, members communicate their wishes to the sergeant-at-arms, who, as soon as he ascertains what is the general desire, issues the requisite order. This rule was found necessary, from the fact that the wants of different individuals are very different in this respect, and that it is the most ultra who are most likely to complain. When the House of Commons first met after the ventilating arrangements were made, one member exclaimed, as he hurried to the door, "The temperature is rising, we shall be suffocated immediately"; and in a moment or two was followed by a second, who said, "I am shivering with cold, I can bear this house no longer." But, besides this difference between different individuals, the same individual is found to vary in his demands during the same evening. In some cases, when the debates have been long, the weather and the number of members fluctuating, fifty or a hundred

variations in the quantity or quality of the air have been made with advantage in the same evening.

The changes in the various circumstances in and out of the House are so frequent and so extensive, that the attendants must be constantly upon the watch to detect them ; indeed, it is said that the same attention is required to give a good atmosphere, as is required of "the sailor in steering a ship." The speaker and the sergeant-at-arms are each supplied with an atmosphere placed under special control. This has been found greatly to simplify the management of the general atmosphere.

The following general rules have been adopted : an increased temperature and diminished velocity before the dinner-hour ; after dinner, other circumstances being the same, a diminished temperature, increased velocity, and reduced amount of moisture ; during late debates, as they advance to two, three, four, and five in the morning, the temperature is gradually increased as the constitution becomes more exhausted, except when the excitement is extreme, and the amount of air diminished, especially if no moisture is required. The highest supply is required in autumn, when the air is warm and moist, the wind light, the barometer low, and the ground damp. Fifty thousand cubic feet per minute are scarcely sufficient then to sustain comfort in a crowded house.

By the constant movement of the atmosphere, promoting a constant and equal evaporation from the lungs and the surface of the body, and by the protection of the

members from all cold and offensive currents, it is found that the amount of coughing is greatly diminished, compared with that observed before these arrangements were introduced.

The best evidence which can be offered of the success of this system, in practice, so far at least as temperature is concerned, under considerable fluctuation of external temperature and number of members, will be found in the following table, which is extracted from those kept regularly by the attendants at the House of Commons.

" *Return of the State of the Three Thermometers, February* 5 *and* 6, *and June* 12, 1839, *placed in the House of Commons in the East and West Side-Galleries, and behind the Speaker's Chair.*

Date.	Hour.	East.	Chair.	West.	Opening of the Ventilating Shutter.	Number of Persons present.
1839.					ft. in.	
February 5	2	61½	61½	61	1 0	100
	3	61½	61½	61	1 0	150
	4	60½	61	61	1 3	120
	5	62½	62	62½	1 6	370
	6	64	64	64	1 6	530
	7	64½	64	64½	1 9	680
	8	64½	64½	64½	2 0	550
	9	65	65	65	2 0	680
	10	66	66	66	2 0	680
	11	66	66	66	2 6	700
	12	65	66	65½	2 0	600
February 6	4	60	59½	59½	1 0	100
	5	63	62	62	1 6	250
	6	63	63	63	2 0	350
	7	62½	63	62½	1 6	220
	7¼	62	62½	62	1 0	100
June 12	3	66	64½	66½	5 0	60
	4	67	65	68	5 0	80
	5	68	66½	69	5 6	180
	6	69	67	70	5 6	220
	7	68½	67	69½	5 6	120
	8	68½	67½	69	2 0	100
	9	69	67½	69	5 6	80

June 12th, ther. in shade 77°; Feb. 5th, 3 P.M., 45°, — lowest during night, 38°; Feb. 6th, 42°, — lowest, 40°.

The heating apparatus, the mild hot-water apparatus now used for the House of Commons, has never given the slightest trouble, acting constantly and regularly for five years, and requiring no repairs.

The arrangements for warming and ventilating the Houses of Parliament will be understood from an examination of the following diagrams.

Fig. 41 is a plan of the heating apparatus and the lower air-chamber. C C C is the receiving-chamber, into which the air first enters, before receiving the desired modification. The cooling apparatus, when required, is placed in C C C, or in the cold-air passage, A. T T is the air-chamber, into which warm air enters from the heating apparatus, *d d e*, in B ; the doors *a a* being shut, while those at *b b* are open. From T T the hot air rises to the equalizing-chamber above.

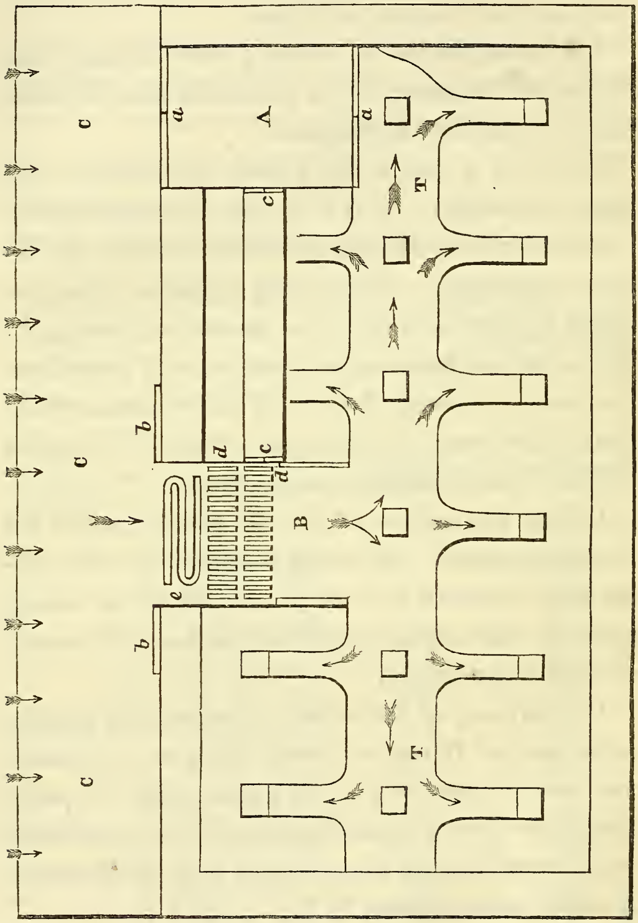
In this arrangement all the air passes through the heating apparatus. By closing the doors *b b*, and opening those marked *a a*, no air passes through the heating apparatus ; the air then enters the chamber T T through the cold-air passage, A.

If a part only of the air is to be heated, the door on either side of B may be closed, those at *c c* opened, and one of those at *a a*. Air then enters A partly through the heating apparatus and partly by *a*, and these two currents, meeting at right-angles in A, are thoroughly mixed before entering T T.

Fig. 42 represents the air as it advances from T T into the equalizing-chamber beneath the floor, after strik-

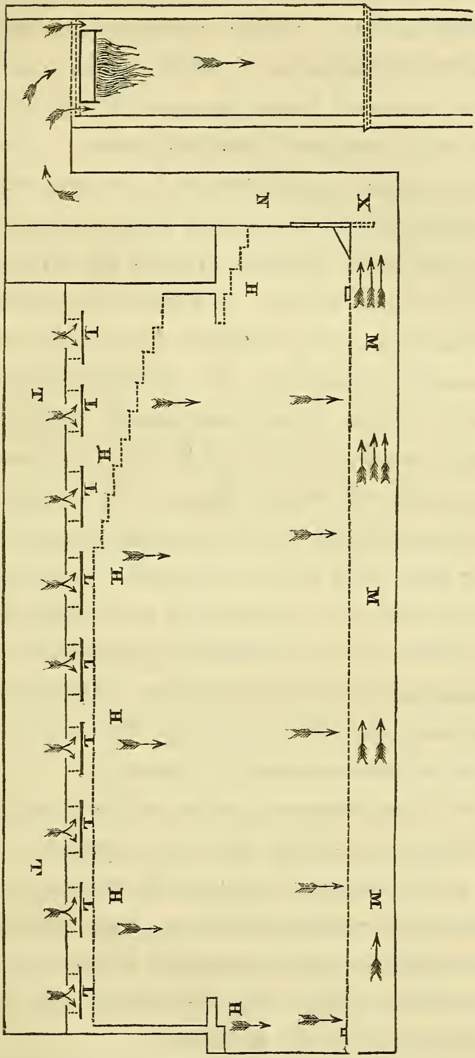
ing upon and being spread out laterally by the dispersers L L L, &c. From this chamber it rises slowly and uni-

Fig. 41.



formly through the apertures in the floor, gradually escaping through the hair-cloth, H H H, &c., from which

Fig. 42.



it ascends through the body of the House to the ventila-

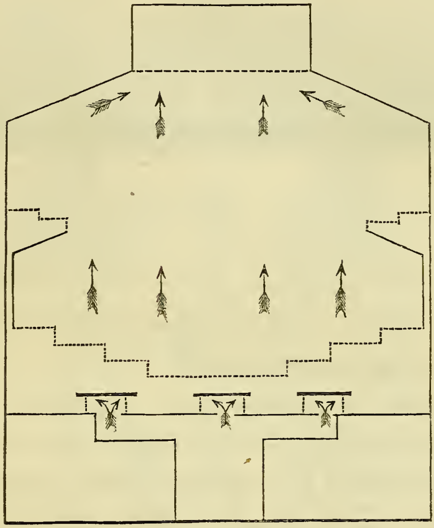
tor, M M M, and descends by the air-trunk, N, to the ventilating chimney. "The rapidity of the movement is regulated by the valve, X, which can be opened entirely, in a crowded house, or closed to any extent, according to the number of members present. The apertures in this upper ventilating-tube increase in number as they recede from the ventilating shaft, a proportionally greater area being required to draw the air from the House in an equal stream. It will be noticed that there are air-chambers, also, below the floor of the galleries, communicating freely with the equalizing-chamber, so that there fresh air is supplied through the perforated floor and porous hair-cloth, H H H, in the same manner as in the body of the House. By bringing down the air from the ceiling to the ground through the descending tube, N, it is not necessary to elevate the shaft so high in the air as would have been required had it been placed on the roof, while the comparative safety of the foundations is also advantageous. But in buildings constructed originally with a view for ventilation it is desirable to have no descent of warm air."

Fig. 43 is a transverse section of the preceding figure. The air rises from the lower chamber, in the direction of the arrows, is dispersed by striking the boards on entering the equalizing-chamber, from which it flows upward to the air-trunk, represented in the section at the top ; on either side are seen the passages near the walls for conducting air to the galleries.

The air enters freely through the whole extent of every

riser on the floor of the House of Commons, and is equalized by the very porous hair-cloth hanging before them. Air is also diffused, and to a still greater extent, by the

Fig. 43.

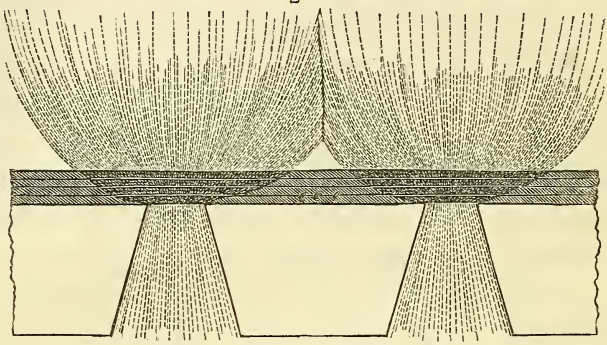


perforations in the floor, the hair-cloth then producing a similar effect, and multiplying indefinitely its diffusion.

Fig. 44 " illustrates the movement of the air through the porous and elastic carpet ; nine tenths of the dust usually introduced into the House by the shoes or boots being excluded by the arrangements in the passages, when they are in full operation. Any other portion pressed upon the hair-cloth either falls through the apertures in the floor, from the form given to them, or, if ground upon the floor between the apertures, it is left untouched at *e e e*, and below the line indicating the pro-

gress of the air." This figure shows the amount of diffusion given at first. The number of apertures was af-

Fig. 44.



terwards doubled. That portion of the hair-cloth most exposed to dust is changed daily.

Fig. 45 is a connected view of the different points referred to, and illustrates the whole progress of the air through the heating apparatus, the House, and the chimney-shaft. "The vitiated air from a drain at *a* in the Old Palace Yard is controlled by the under-ground ventiduct, and conveyed directly to the shaft. *b* is the fresh-air entrance, where the air is taken from Old Palace Yard, and within it is the suspended fibrous veil, forty-two feet by eighteen feet, for excluding mechanical impurities ; *c*, the temporary apparatus for moistening or washing the air ; *d e*, the hot-air chamber communicating with *e*, the lower air-chamber, which receives warm, cold, or mixed air, according to the temperature required ; *f f*, deflectors for diffusing the air in the equalizing-chamber, *g g* ; *b b*, the supply for the galleries,

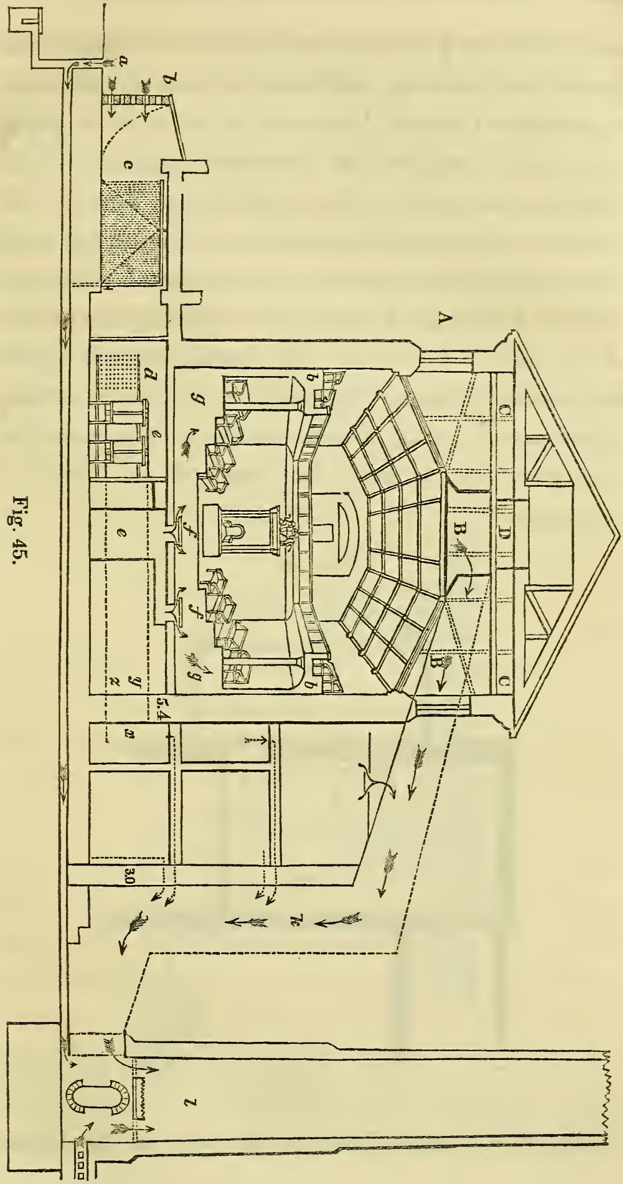


Fig. 45.

conveyed from *g* by the channels between *b* and *g* ; the dotted lines above *y* and below *z* show the flow and return-pipes from the hot-water boiler, which is placed at *x*, which supplies the hot-water apparatus in *d e*. The large arrows from the ventilating chamber, B, indicate the progress of the air from the ventilating shaft, while small arrows indicate the discharge of vitiated air from the libraries and various other places in the vicinity of the shaft. A indicates the external windows ; C C, the original altitude of the ceiling ; and D, the vitiated air-channel from the House of Peers, communicating ultimately with the shaft that ventilates the House of Commons."

Fig. 46.

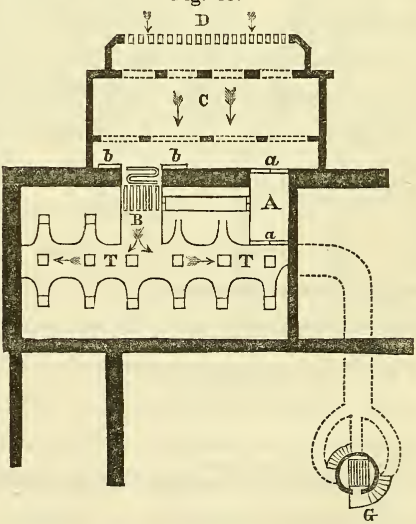
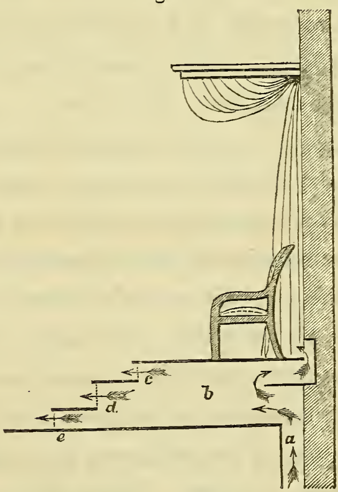


Fig. 46 is a ground-plan of the cellar of the House

of Commons, in which the same letters refer to the same parts as in the preceding plans. D is the entrance for the fresh air ; C, the outer air-chamber, in which the veil is suspended ; B, the warming apparatus ; T T, the mixing-chamber ; A, the cold-air passage ; *a a*, *b b*, the doors controlling the passages ; G, the chimney, connected by the under-ground channels, represented by the dotted lines, with the vitiated-air flue over the House of Commons.

Figs. 47 and 48 are a plan and section illustrating the ventilation of the throne, and may be taken as an exam-

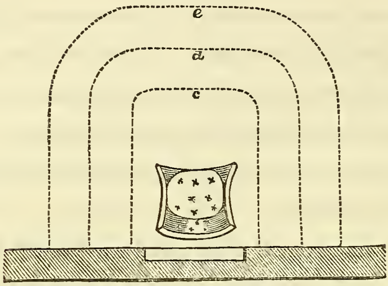
Fig. 47.



ple of the mode of ventilating the speaker's chair, or a pulpit in a church. The throne is ventilated by special arrangements, controlled at the air-channel, *a*, which

supplies the chamber, *b*, from which the fresh air is diffused around the chair, at *c d e*, or other places.*

Fig. 48.



New Houses of Parliament. — The plan proposed for the ventilation of the Houses of Parliament now building was reported by a committee of the House of Commons, in 1841. How much of this plan has been adopted we have not been able to learn.

The air, according to this proposed plan, is to be taken from a height of 200 feet, by two towers, the clock-tower and the Victoria tower, which are to be situated at opposite extremities of the immense pile of buildings constituting the new Houses of Parliament. The design in taking air from this great height, and from two sources, is to escape the various impurities which usually exist near the surface of the earth, and to use one or the other source, as the wind may drive smoke or impure air towards the other. From these towers the air

* A full description of the ventilating arrangements of the temporary Houses of Parliament, with numerous illustrations, from which the above has been derived, will be found in Reid's Illustrations of Ventilation.

is conducted to a basement story, between the foundation walls, which extends under the whole building. This immense area is expected to afford, in warm weather, a magnificent reservoir of cool air for the supply of the halls above.* In the basement, also, is to be placed the warming apparatus, the mechanical power, and all the horizontal flues connecting with the upright flues conducting to the various apartments.

After the air has been properly tempered in the basement, it is to be allowed to ascend into the public hall above, and into the committee-rooms. In the committee-rooms, the air entering which is to be only moderately warmed, are to be open fires, fed by coke or other smokeless fuel. All the ventilating and smoke-flues of these apartments, to the number of about 400, are to be carried upon a fire-proof floor under the roof to a ventilating tower or spire over the central octagonal hall. This tower, which is to be 250 feet above Trinity high-water mark, is to be the sole egress and the principal moving power to the whole system.

Provision is to be made in this tower for making a fire, if it shall be found necessary ; but it is hoped that the plenum movement derived from the natural current of the wind, by which the air is forced inwards, aided by the rarefaction of the air, when heated in the various apartments, by which it flows outwards, will, in most cases, produce a sufficient ventilating current in

* In the temporary Houses of Parliament it is stated that the expense of cooling the air by any arrangements which have been heretofore adopted has been from five to ten guineas daily.

the lofty tower. When the Houses are much crowded, it is intended to make use of mechanical means to propel the air, and prevent indraughts at the doors.

As the large halls are used in the evening only, and the committee-rooms in the day-time, it is proposed to use upon the committee-rooms the same power which at other times would be devoted entirely to the halls.

The following is the estimate of the expense of the warming and ventilating arrangements of these buildings, machinery being provided to assist solely in the ventilation of the Houses proper.

1. Air-flues under the basement, &c., and under all the floors, including the vaulting of the basement, and communicating channels in the roof, leading to the central shaft,	£ 12,320
2. Apparatus for warming, purifying, propelling, and regulating the admission of the air,	12,000
3. The central shaft, ...	20,000
4. Fire-proof floor under the roof, to simplify the general construction of the flues, and permit them to be discharged by a central shaft, ...	20,680
Total, ...	£ 65,000

Estimated cost of central tower, . .		£ 20,000
If dispensed with, deduct, for cost of additional flues and other necessary arrangements, . . .	£ 10,500	
Also deduct for cost of machinery,	4,000	
		14,500
Saving of expense as to outlay,		£ 5,500

From this estimate it would appear that some saving of expense could be made by dispensing with the central tower, and propelling the air entirely by machinery, allowing it to escape at numerous points, wherever it may be found to be most convenient. But it is believed that this saving will be materially reduced by the cost of additional attendance which will be necessary if the tower is not adopted. The plan recommended by Dr. Reid is distinctly that of a large central tower.

French Chamber of Peers. — This hall is a semicircular apartment of about thirty-two feet radius, having spectators' galleries upon the sides. The air for ventilating and warming it is taken from a garden at a little distance from the building by an opening of about ten square feet in area, and, after passing through an under-ground air-channel, enters two fans seven feet in diameter, and five feet wide, with six vanes, by which it is driven onward to four hot-air stoves, or *calorifères*. After being sufficiently heated, the air passes under the floor of a guard-room, which it warms, and ascends by passages in the walls to a space under the floor of the Chamber of Peers, into which it finds its way through openings in all the risers of the steps. Near the points at which the warm air escapes into the Chamber, plates of cast iron are inserted into the horizontal part of the steps, which are heated by the air. In summer, air is driven into the Chamber, through the same apertures, by four other ventilating fans, of the same dimensions as those just mentioned.

The vitiated air escapes by an opening over the chandelier, and by other openings at the upper and back part of the galleries ; that from the last-mentioned openings passes along the attic to the trunk over the chandelier, and escapes with it into the external atmosphere.

In the mode of warming adopted for this building, the object of M. Talabot, who arranged it, was to heat the whole mass of the buildings ; this kept up a pretty constant temperature, but, as they were spread over a large surface of ground, it was attended with a very great loss of heat.

Several experiments were made to determine the amount of ventilation, when produced by the ascent of the warm air, aided by the action of the chandelier ; it was found to be about 425,700 cubic feet per hour. Supposing the Chamber to contain 600 persons, this would give about 700 cubic feet per hour for each individual, or nearly twelve cubic feet per minute.

The summer ventilation is produced by means of the four fans above mentioned. Each pair of fans moves together, and is put in action by two men. The openings in the centre are thirty-one inches in diameter. When moving with their usual velocity, they throw into the Chamber about seven cubic feet per minute for each individual.

These arrangements were reported, by a committee composed of Thenard, Gay-Lussac, Pouillet, and Péclet, to be satisfactory, and the ventilation sufficient.

VENTILATION OF THEATRES.*

In most theatres the principal entrance of air is from the stage. When the curtain is raised, the air from the stage is often felt blowing over the pit, like a cold, chilling wind, and this, occurring after the audience has become heated, cannot but be injurious. The same movement brings with it the noxious exhalations from the foot-lights and other means of illumination upon the stage.

It is important to bear in mind that the mode of ventilating may have an influence upon the sounds passing from the stage to any part of the house, and may even render them inaudible in some parts. It has been observed, that, if a large mass of heated air, or air otherwise altered in density, intervene between the speaker and auditor, the sounds of the voice become less distinct, and, in some cases, very much confused. To give the best intonations, a uniform state of the atmosphere, as regards density, appears important, independently of any particular form of a building and its materials, and that the atmosphere should be quiescent, or, if in motion, that it should be gentle, and towards the auditor. Large and unmasked openings in the ceiling may also materially injure the sound. In a chapel, an opening for ventilation was made in the ceiling of an organ-

* Whatever may be our views as to the moral influence of theatres, we presume there can be no doubt as to the propriety of removing in every possible way all physical evils to which those frequenting them may be exposed, from faults of construction or management.

loft, directly over the organ; when the chapel was crowded, and the current through the opening considerable, the organ became nearly inaudible to those upon the floor. The difficulty ceased immediately on closing the opening.

If the emanations from the foot-lights were removed by either of the methods pointed out in the section on Exclusive Lighting, page 69, a simple and tolerably efficient mode of supplying air might be adopted. A large quantity of warmed air could be poured into the space at the back part and sides of the stage, which could be made to pass over the audience on its way to outlets in the ceiling at the opposite extremity of the house. This, however, cannot be considered as the most advisable mode, since the air will be pure to those only who are near the stage.

In all well constructed theatres, the entrances to the pit and boxes are from corridors which surround them. In these corridors the heating apparatus should be placed, or warm air should enter them by proper flues from hot-air furnaces or other means of warming, placed beneath. From the corridors, the air thus tempered will enter the avenues to the pit and the doors of the boxes, when open; when the doors are closed, the air should find its way into the boxes through openings in the back part, near the ceiling, or through holes in the wall, near the floor. By these means, a constant current will be established, which will prevent the air arising from the body of the house from entering the box on the one

side, or cold blasts of air from the corridor on the other. For the pit, numerous openings should be made under the seats, or in other parts not covered by the feet, through which moderately warmed air can be admitted.

The moving power in a theatre thus ventilated is the heat evolved from the audience, and that from the chandeliers. Over the principal chandelier a large trunk should be erected, rising some feet above the roof, opening into the external atmosphere, and covered by a fixed or revolving cowl. The lower orifice of this trunk should be masked by a centre-piece, either falling below the level of the ceiling, or rising above it, allowing most of the air to escape by the edge of the centre-piece, a part only passing through it. Such an arrangement not only adds to the beauty of the ceiling, but will prevent a great loss of sound. Trunks from those parts of the ceiling over the other chandeliers should lead to the main trunk, and enter it above the ceiling.

A separate trunk should be provided over the stage, to which the vitiated air from the foot-lights, and the smoke from the materials used in the various representations, may be drawn. In both this and the main trunk should be placed valves for controlling the movement of the air.

Many years ago, the Marquis de Chabannes contrived a system of warming and ventilating, which was successfully applied to Covent Garden theatre. Stoves were placed in the staircases and at the entrances, by which they were thoroughly warmed, and all unpleasant draughts

obviated. The influx of cold air from the stage was prevented by similar means. But, instead of stoves, which would be objectionable on account of the inflammable nature of the machinery, he used steam-cylinders, forty-four in number, each traversed by thirty two-inch pipes, through which the air passed and was warmed. The steam was supplied by a boiler securely placed in a vault near the stage-entrance. As a moving power, in addition to the chandeliers, which contained eighty bat's-wing burners, and which was suspended under a funnel terminating upon the exterior of the building, he made use of a *ventilating furnace*, placed in the lower gallery, through which the air from the building passed and was rarefied, before it entered a large, upright trunk, on its way to the external atmosphere.

VENTILATION OF CHURCHES.

During the winter, the change of air consequent upon the great difference of temperature between the internal and external air is generally sufficient for the number usually assembled in churches. They are commonly lofty and capacious, and afford a magazine upon which the audience may draw during the hour it is usually assembled, and, if proper care is taken to open the doors or windows between the services, a sufficient change of air will be produced before the audience returns. When the church is small, and much crowded, especially in the evening, when a large amount of foul air is produced by the means used for lighting, and when, also, it is warmed

by close stoves or other radiating bodies within it, such an amount of ventilation will be found altogether insufficient, and it becomes necessary to adopt special arrangements.

A serious inconvenience, experienced by all who sit near the large windows of churches in cold weather, is the descent of cold air upon their heads, and the various local currents which such a movement inevitably produces. This inconvenience can be obviated only by introducing double glazed windows, or some translucent material stretched upon a frame, which shall act as a tight curtain, and prevent the warm air from coming in contact with the external glass windows.

It has been proposed, of late, to close all side windows, and illuminate entirely by the roof. In cities, where it is difficult to obtain sufficient space around a church to command a free supply of air, such an arrangement would be particularly advantageous. The money that is now so frequently, in this country, expended in ornamenting an exterior, which cannot be seen, could be devoted to beautifying the interior in a manner suited to the devotional spirit which it should be the object of all such decorations to encourage. The front, if in a situation to be well seen, would still afford quite as much space for architectural display as could be profitably used, and might be crowned by a steeple or tower, which would be an important aid to systematic ventilation.

A church illuminated in the manner just mentioned

should have no galleries to interfere with the light descending from the ceiling ; if, however, an old building is to be so arranged, and it is desirable to retain the galleries, the ceiling should be brought down, and the windows made above it, in the upright walls, but low enough to allow the light to pass under the galleries and fall upon the wall, from which it would be reflected directly upon the books, when held in the usual position.*

A system of ventilation will of course be essential in a building thus constructed. In a church with the usual number of windows, which are also to be used for ventilation, proper apertures for the admission of air will be found much more healthy and agreeable. For, if a window be opened when the air within the church is warmer than the external air, — and it is under such circumstances that windows are most frequently opened, — and this window be at some height above the floor, on the shaded and consequently colder side of the house, air will enter by it, and fall upon the heads of those sitting at a little distance from the wall, on its passage to another window on the opposite side. This current will be stronger and more offensive, the higher the point at which it escapes from the building.

A plan which is found to answer well, and is easily put in execution, is to admit the air to the cellar, from a

* From inattention to this point, of admitting the light low enough down to allow it to pass under the gallery, it was found necessary, in a church in which the side windows had been closed, to cut other windows under the gallery, before sufficient light could be obtained for those sitting there.

sufficient height above the ground to exclude dust, — from the lower part of the tower, for instance, — and, after allowing it to pass through the heating apparatus, or not, as circumstances may require, admit it to the body of the church through a sufficient number of openings in the aisles. To the galleries, if necessary, flues of sufficient size may be carried up in or against the walls, and open with a suitable amount of diffusion. To the pulpit a separate flue may be appropriated, the air from which may enter under the seat, or from the front of the desk, on the inside. This flue should have a valve, under the control of the clergyman. The outlet should be at the ceiling, from one or more points connected with a trunk leading to the top of the tower or steeple. This trunk, also, should be fitted with a valve, for the long column of heated air which will be thus formed will often be much greater than is required. When the church is heating, this valve should always be closed.

Mr. Tredgold, in his work on the Principles of Warming and Ventilating Public Buildings (a work which seems to have been strangely forgotten by recent writers on this subject), proposes, in new buildings, that they should be constructed with flues for cold air down the piers between the windows. The air could then enter at openings in the frieze under the cornice, pass down a smooth flue, and beneath the floor, to rise in the church through gratings in the floor of the aisles ; and by disposing some of these flues on each side of the church, they would act with the wind in any direction. From

the floor the air would rise to the centre-piece, the opening in which could be masked by a shield, and escape through a common luffer-boarded outlet on the roof, if the building is destitute of steeple and bell-tower.

In a few churches in this country, the old practice of constructing tombs beneath them still continues. We cannot enough insist upon the deleterious influence such a custom must have upon the health of those frequenting the church ; whatever care is taken in the construction of a tomb, some of the gases will escape, be diffused in the air of the vaults, and find its way into the church. It is to be hoped that soon the influence of the beautiful cemetery at Mount Auburn may produce a right feeling on this subject in the community, and prevent this revolting custom of mingling the living with the dead.

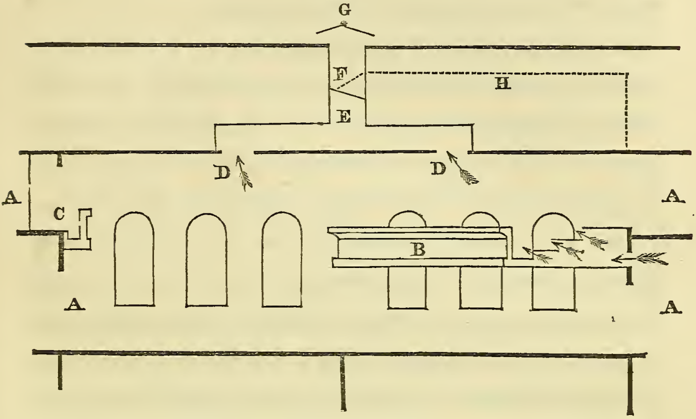
In chapels, which are smaller and more liable to be filled or crowded than the larger churches, ventilating apertures are more important than in churches. Frequently, the gallery or orchestra of a chapel is above the windows ; consequently, all change of air in the gallery is effectually cut off by these openings.

In the College Chapel, at Cambridge, Massachusetts, the galleries are constructed as just mentioned ; and those sitting in them were formerly much annoyed by the heat and closeness of the air, or, when the doors of the gallery were open, by the blast of cold air from them.

Fig. 49 is a section of the Chapel, in which A A, &c., represent the entries ; B, the gallery which occupies the end, and half the two adjacent sides, of the walls ;

C, the orchestra. It will be seen that the greater part of those sitting in the gallery, and all those in the orches-

Fig. 49.



tra, are above the window-tops. The ventilation is effected in the following manner. D D are two open centre-pieces, masked by foliage, each four feet in diameter, connected by two branch trunks, four feet wide by two and a half high, with the main trunk, E, four feet by the side; this trunk is fitted with a valve, F. The vitiated air escapes from beneath the cowl, G, which is open around its whole circumference. H, the cord attached to the valve, F, which descends to the gallery.

LECTURE-ROOMS.

In the buildings just described, the apartments have been supposed to be large, and the numbers usually assembled in them great. Lecture-rooms form another

and more numerous class of rooms, for which some simple and efficient plan of ventilation should be pointed out. At present, very few rooms of this kind are provided with arrangements for this purpose.

One of the simplest plans which can be devised is, to make openings in the walls of the building, by which fresh air may enter between the floor of the lecture-room and the ceiling of the room below. If the room is upon the lower floor, or the apartment below is not ceiled, air may be led through the same openings, by means of trunks, to such an extent under the floor as may be found necessary. If the building is constructing, this last plan could be adopted with little expense, and would be found the most economical arrangement, as regards heat, when the room is to be warmed as well as ventilated, unless the rooms below are also warmed and communicate heat through the ceiling to the air above it. From this space below the floor, or from the trunks, air is to be admitted through the risers of the ascending steps, and from the front of the lecturer's platform. If the seats are placed upon an inclined plane, and not upon steps, openings must be made through the aisles and other vacant spaces, through which the air may ascend. These openings must be fitted with registers, in order to close them while the room is swept. The outer openings in the walls, or the main air-trunks leading from them, should also have valves.

The outlet must be in the ceiling, and sufficiently large to afford a free passage for all the air. This open-

ing can be masked by a centre-piece of stucco-work, leaving an open space around its edges and through its leaves. If the centre-piece is raised above the level of the ceiling six or eight inches, a pretty large space may be obtained at the edges without injuring its appearance. This plan will be found more effectual than making two or more openings in the ceiling, and connecting them with a main trunk in the centre.

Above the centre-piece an air-trunk must be placed, communicating directly with the open air ; and in it a valve which will close it perfectly. This valve can be moved by means of a cord passing into the room below, or to some place near it, of ready access. The top of the air-trunk may be covered by a revolving cowl or a fixed cap. The first will be found most efficient in preventing the entrance of rain, but will be open to the objection of producing a noise as it revolves. The second, being fixed, will produce no noise, and, if properly constructed, will not often admit rain.

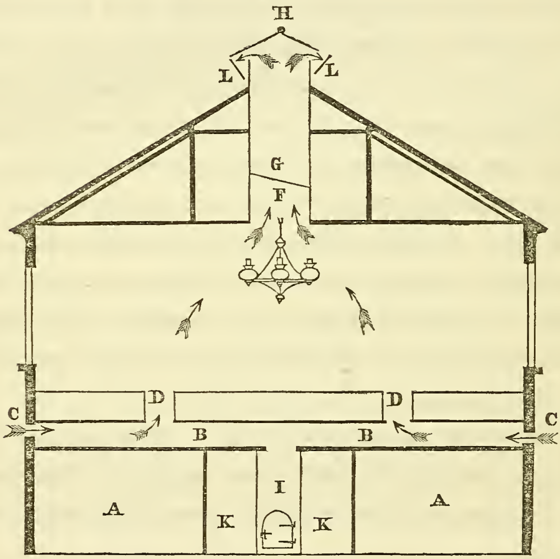
The moving power in this plan is the warmth of the vitiated air, and the heat given out by a chandelier, which is supposed to be placed immediately under the air-trunk.

The air is supposed to be admitted from without, and to be neither warmed nor otherwise tempered ; consequently, it is not well adapted for the cold weather of winter, but will do well during the other seasons of the year. In the winter, the openings in the walls may be closed, and the air admitted beneath the floor or into the

trunks above mentioned, after passing through any form of hot-air furnace, placed in any apartment beneath the lecture-room. The heat of the entering air may be diminished at any time by opening one or more of the openings in the walls.

The following figure (fig. 50) represents a cross-section of the Lyceum Hall, Cambridge, Massachusetts,

Fig. 50.



with the plan recommended for ventilating it. A A are stores beneath the hall; B B, the space between the ceiling of the stores and the floor of the hall; C C, openings in the outer walls, giving free access for the air to the sapce B. D D, the aisles, in which are the openings through which the air finds its way into the hall. F,

the vitiated-air flue ; G, the valve closing the air-flue. This valve is moved by means of a cord, descending to the entry just outside the hall-door. H, the cowl, which is fixed to the top of the air-flue, leaving an open space of about nine inches between it and the cowl ; the cowl projects over the air-flue about one foot. On either side of the flue is an inclined board, L, about ten inches wide, placed nearly at right angles with the roof. It is found necessary to surround the air-trunk with this board, to prevent the wind, when blowing against the side of the roof, from passing up under the cowl and preventing the escape of the vitiated air. The wind, by this arrangement, is so far diverted from its original direction, that it passes over the cap, and assists somewhat in exhausting the air. K K is the entry, in which is placed the stove, I, inclosed in a case, between which and the stove the air can pass up into the space between the floors, and thence into the hall. It was intended that the greater part of the air, in winter, should pass through this warming apparatus, a small part only of the apertures in the walls being allowed to remain open. Thus far, however, the stove has never been placed in the entry, and the ventilation has been supplied with cold air. The moving power is the chandelier, represented under the flue, and the vitiated air from the hall.

SCHOOLHOUSES.

As much of the time of the young is spent in school-

houses, we cannot bestow too much attention either upon their construction or their management. The situation, where it can be selected, should be upon a dry, gravelly, or sandy soil even, rather than upon one which is damp, and suited to luxuriant vegetation. Those situations which have been described in some works on education, upon the borders of a pond or lake, the building itself surrounded and half hidden by the thick foliage of trees and shrubs, may be very pleasant to look at, but are very different from those which a prudent regard for health would have pointed out. Trees overhanging a building, by the exclusion of the sun and air, and the consequent retention of moisture after rains, are injurious both to the permanency of the building and the health of the occupants.

While schoolrooms were constructed with open fireplaces, in which wood was burned, sufficient air passed through the chimney to preserve the atmosphere in a tolerable state of purity. In the neighbourhood of large cities, as firewood has become more expensive, coal has been substituted, the fireplaces have been closed, and their place supplied by stoves. As very little air is required in the combustion of the fuel in stoves, the amount of ventilation has been proportionally reduced, until it has become altogether insufficient for the number of children usually assembled.

Although we may change the air of schoolrooms in the morning and between schools, by opening windows and doors, still this can be done only at certain seasons

of the year, and even then not without the inconveniences which must be produced by wind or rain. The schoolrooms are not usually sufficiently large to contain the amount of air required by the children during the session; consequently we find, in most cases, after an hour or more, the air becomes heavy, and its odor unpleasant. It is impossible that the health of teacher and pupils should not suffer from remaining day after day in an atmosphere thus vitiated.*

---

* My attention was some time since drawn to a number of children who suffered from frequent coughs and colds in the head. They all belonged to the same school, and, on inquiring at the schoolroom, it was found that this room was fifteen feet long by ten feet wide and twelve feet high, containing, therefore, about 1800 cubic feet, inclusive of the seats and other fixtures; it was warmed by a small box-stove, the funnel of which was thrust through the window. The number of children occupying this room was from fifty to sixty; they were seated along one side of the room, near the only window. As the heat was often great, this window was frequently opened, occasioning, by the entrance of cold air upon the heads of the children, the colds just mentioned. Notwithstanding the odor of the air was sometimes quite disagreeable, it was very difficult to convince the Committee, whose duty it was to attend to the matter, that there was any thing unhealthy in such a state of things. One person to whom the fact was mentioned remarked, in extenuation of the evil, that they were "very small children."

This state of things, however, is not so bad as that of some of the schoolrooms in Liverpool, England. Mr. Riddal Wood, in his Report on the Schools, says, "Of the common day schools in the poorer districts it is difficult to convey an accurate idea. So close and offensive is the atmosphere in many of them, as to be intolerable to a person entering from the open air, more especially as the hour for quitting school approaches. The masters and mistresses were generally ignorant of the depressing and unhealthy effects which surrounded them. The mistress of a dame school replied, when they were pointed out to her, that 'children thrived best in the dirt.' One school was in a garret,

Where hot-air furnaces are used, the air is admitted at such a temperature that it rises to the ceiling, and does not come in contact with the organs of respiration until it has been contaminated by the air already breathed.

The mode of supplying sufficient air will of course depend upon the warming apparatus. If a hot-air furnace is used, the principle of distribution should be adopted, as far as possible, with a due regard to economy of heat. As hot-air furnaces are usually constructed, the top of the hot-air chamber is covered by a large, flat stone ; this stone is placed, in some cases, immediately under the floor, and by the heat thus communicated several schoolhouses have been burned. A better arrangement, as regards both safety and convenience, would be to carry the brick walls of the furnace *through* the floor, and lay the stone upon them even with it, and, about four inches above this stone, to place another of the same size. The warmed air would then rise through the proper opening in the lower stone, be spread out between the two, and escape at the edges. By this means a larger amount of diffusion would be obtained, and a better opportunity afforded for warming

---

up three pair of dark, broken stairs, with forty children in the compass of ten feet by nine, and on a perch forming a triangle with the corner of the room sat a cock and two hens. Under a stump bed, immediately beneath, was a dog-kennel, in the occupation of three black terriers, whose barking, added to the noise of the children and the cackling of the fowls on the approach of a stranger, was almost deafening. There was only one small window, at which sat the master, obstructing three fourths of the light it was capable of admitting."

those who enter from the cold air, or who have cold feet. A similar plan could be adopted in the second story for distributing the air; or a horizontal metallic trunk could be placed near one side of the room, or beneath the lower step of the reciting-platform, from the front of which, through numerous small openings, the air might escape.

The foul-air channels, with the arrangements here indicated, must necessarily have their orifices in the lower part of the room, within three or four feet of the floor; otherwise it will be impossible to warm the room. In summer they should terminate at the highest point, at the ceiling. In both cases these channels must have a free outlet into the open air, and be covered by a cowl.

They should not terminate in the attic. By allowing them to terminate here, the air from them is often diffused under a cold roof, becomes cold, and may even find its way, by means of staircases or spaces in the walls, into the room from which it escaped. We examined, not long since, a schoolhouse in which there were twenty-four flues for the escape of the foul air, eight by twelve inches each, terminating in the attic, in which four other flues, about fourteen inches square, or about one third the area of the first flues, were constructed against chimneys connected with the hot-air stoves in the cellar, and opened into the air with these chimneys. The lower openings of the four flues were about four feet above the floor of the attic. The object undoubtedly was to make use of the waste heat of the hot-air stoves as a

moving power ; to do this, the flues from the several rooms should have been carried directly to the flue in contact with the chimney, or even carried down near the bottom of the chimney, by which means a longer column of warmer air would have been obtained. As then arranged, by far the greater part of the movement due to the heat of the foul air was lost.

Most schoolrooms are warmed by stoves placed within them. These can be converted into means of ventilation, by surrounding them with a sheet-iron case, open at the top, and furnished with a door opposite that in the stove, by which the fire may be renewed, and another at the bottom, and at the back, through which the air may pass into the space between the stove and case. Beneath the stove should be a tube leading to the outside of the building, through which air may enter the room after passing through this same space. This tube should be furnished with a valve.

When it is required that the room should be warmed only, the door is opened in the back of the case and the valve in the tube closed ; the air of the room thus circulates through the stove. When the room is to be ventilated as well as warmed, the door is closed, and the valve in the tube opened. The stove will be described in the second part of this treatise.

As the case will never become very hot, it will prevent children from being burned by falling against the stove, and will also protect those who may sit near it from too great heat. The stove should be placed at

the end of the room opposite to the chimney, with which it should be connected by means of a sheet-iron pipe. If this pipe be carried to a sufficient height within the chimney, the chimney could be used as a ventilating-flue, without injuring the draught of the stove.

The openings into the chimney, if used as a ventilating-flue, may be at two levels, — the one about four feet from the floor, and the other near the ceiling; the latter being used when the room is too warm and when a large amount of ventilation is required. The chimney should be built somewhat larger than will be necessary to carry the smoke alone, and, if sufficient space can be obtained, the ventilating-flues may be partitioned off from and be arranged around the smoke-flue. The ventilating-flues will then be warmed by the smoke, without any injury to the draught of the stove; we shall also avoid the inconvenience of replacing the smoke-pipe in the chimney, which must frequently be done, especially if wood is burned.

A somewhat similar mode of warming and ventilating schoolhouses was recommended some time since.* By this mode it is proposed to construct a double-back fireplace of brick, making the space between the walls about four inches deep, and carrying up the brick casing six or eight inches above the top of the fireplace, leaving openings in the sides, near the top, through

---

* The Schoolmaster. The proper Character, Studies, and Duties of the Teacher, &c., and the Principles on which Schoolhouses should be built, arranged, warmed, and ventilated. By George B. Emerson.

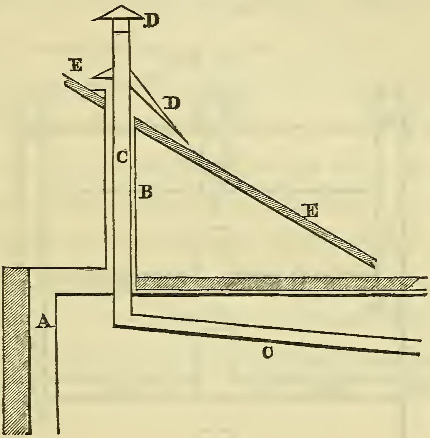
which the heated air may enter the room. The hollow back is supplied with air by a trunk communicating with the outside of the building. This trunk is twenty-four inches by six or eight, and laid beneath the floor. The brick chimney, which it is directed should be built two or three feet above the hollow back, is covered with a flat stone or plate of iron, and from this a metallic smoke-pipe rises one foot, then passes to the opposite extremity of the room, when it ascends perpendicularly and issues above the roof. The fireplace is to be provided with doors, by which it may be completely closed. A slight addition would make this fireplace a more efficient heating apparatus, and in no way diminish its efficacy as a ventilating machine. An opening should be left at the back of the casing, commanded by a door and a valve placed in the air-trunk. By means of these, the air of the room could be warmed by circulating in the hollow back before the pupils entered, and the external air be introduced after the session began.

In the same plan it is proposed to produce ventilation beyond that going on through the fireplace, by surrounding the stove-pipe with a tube of tinned iron, opening into the air through the roof. The lower part of the tinned iron tube communicates with a wooden trunk opening near the floor ; through this it is supposed an upward current will always take place when the smoke-flue is warm.

The following diagram, fig. 51, illustrates the ventilating apparatus. A, air-box, one foot square, covered

by the pilaster, and opening at the floor in the base of the pilaster. B, round iron tube, 15½ inches in diameter, being a continuation of the air-box. Through the centre of this box passes the smoke-pipe, C, eight inches in diameter. D, the caps to keep out rain. These

Fig. 51.

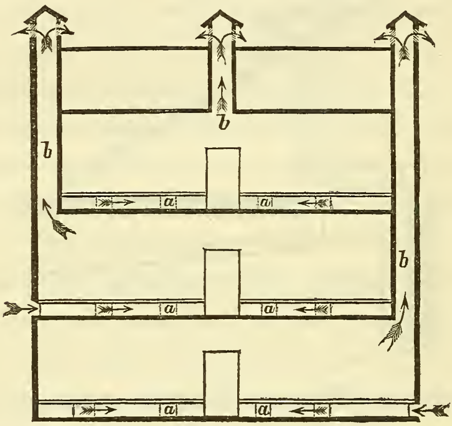


caps should be differently arranged, or the pipe should pass through the ridge-pole of the building. With the present arrangement, a wind blowing against the roof, E E, would be very liable to pass under the cap, and prevent any escape from the air-trunk, B.

During the summer, inlets for the fresh air, and an outlet for that which has become vitiated, should be provided, sufficient for ventilation, without exposing the pupils to draughts from windows or doors. Fig. 52 illustrates one of the modes which may be adopted. The rooms are supposed to be destitute of all means of

ventilation except by doors and windows, and without an entry, the entrance being by an external staircase. The base or mop-board is to be set off from the studs two or three inches, if it is a wooden building, and pieces of board placed between the studs, above the base, to cut off all communication with the space between the walls; openings are then to be made through

Fig. 52.



the sides of the building to allow a free passage for the air into the box thus formed behind the base; the base must then be pierced with holes three quarters of an inch in diameter, through which the air may enter the schoolroom. A sufficient foul-air trunk should lead from the ceiling into the open air, if possible, through the highest point of the roof; if this cannot be done, the trunk should rise sufficiently high above the roof to avoid the influence of eddies and downward movements of the wind.

If the schoolhouse be surmounted by a belfry, the sides may be *luffer-boarded* (fitted with broad slats, as in window-blinds), and the foul-air flue terminate in it. The openings in the sides of the building, and the foul-air trunks, should all be fitted with valves. In the figure, *a a* represent the points of ingress, and *b b b* those of egress.

A much more common case is that in which the schoolhouse has an entry, into which the air freely enters. We may then admit air to the schoolroom by having a light door-frame fitted to the door, and covering it with a coarse, loose fabric, *millinet*, or with the perforated zinc now in common use for window-shades, through which the air will pass freely, but in a diffused manner. In this case, also, the room should be provided with a free outlet for foul air, opening near the ceiling.

CHAPTER XIII.

VENTILATION OF PRISONS AND HOSPITALS.

Distinctive Characteristics of the Auburn and Pennsylvania Discipline. — Auburn Prisons. — State Prison at Charlestown, Massachusetts. — Means of Ventilation insufficient, especially in warm, sultry Weather. — Convicts often sent to the Hospital from this Cause. — No Moving Power in the Auburn System, a System of Flues only. — Undue Importance attached to Flues without Moving Power in Reports of Prison Discipline Society. — Theoretical and practical Value of Flues compared. — New Penitentiary at Philadelphia without Moving Power. — Insufficiency of Flues only in this System. — Description of the Model Prison at Pentonville. — Modification of this Plan required to adapt it to the Climate of New England. — Ventilation of Hospitals. — Its great Importance. — General Hospitals. — Asylums for the Insane. — Arrangements of the General Hospital must be varied to fit them for Asylums for the Insane. — Provisions to secure Flues from Obstruction, Contamination, and Injury.

In this country, the prisons are constructed and managed in a great variety of ways. The two principal modes are those after the Auburn system and the Pennsylvania system. The distinctive characteristics of the former are, that there is supposed to be no communication between prisoners, except with regard to their work in the shops. During the night, each prisoner occupies a separate cell. In the latter, there is supposed to be not only no communication between the prisoners, but they are never allowed to see each other. Each prisoner oc-

cupies a separate cell, both day and night, and at certain times only is allowed to amuse himself in a small exercising-yard connected with his cell. His cell is thus made "his work-shop, his bed-room, his dining-hall, his water-closet, his chapel," &c. A third mode of confinement is found throughout the country, but is most frequently met with in the jails, in which each cell contains many prisoners, and usually without employment. With regard to the Auburn and Pennsylvania systems, warm discussions are, and have for several years been, carried on by their respective friends; with them we have nothing to do, nor with the influence these systems may have upon the health of the prisoners. It is obvious, however, that persons confined in a small apartment will require a greater supply of air, and a better system of ventilation, than those who work during the greater part of the day in the open air, or in a large, open workshop.

Of the prisons upon the Auburn plan, we may take that at Charlestown as the type. This structure is double, constituting, in fact, a building within a building. The outer building is about two hundred feet long by forty feet wide. Within this building is a centre wall, two feet in thickness, on each side of which the cells, three hundred in number, are arranged. This wall, with the cells, forms a block, leaving a corridor between it and the walls of the outer building, ten or twelve feet in width. The walls between the cells are one foot in thickness; those between the cells and the open area or corridor, in which are the doors, two feet.

The cells are seven and a half feet long, seven feet high, and three and a half wide. The only opening from the cell, except the ventilator, is the door, in the upper end of which is the iron grate, about eighteen by twenty inches. The bars of this grate are round iron, three fourths of an inch in diameter, placed about two inches asunder, leaving orifices smaller than a man's hand. Through this grate all the light, heat, and air are admitted to the cells. The ventilator, which is about three inches by four, extends from near the ceiling at the back of the cell to the attic, where several unite in a common chimney, through which the foul air is supposed to escape into the open atmosphere. In some prisons upon this plan, it is said the flues terminate in the attic, from which the vitiated air escapes by one or more openings. The area or corridor around the cells is open from the ground to the ceiling, in front of four stories of cells. The different stories are gained by flights of steps at either end, from which any cell may be reached by a gallery three feet in width, and extending from end to end of the block.

There are no windows in the wall of the outer building opposite the lower range of cells; but above, on this plan, it is intended that there shall be a window opposite each cell.

This prison is warmed by four anthracite-coal stoves, one of which is placed in each corner of the corridor. These are sufficient, it is said, to keep the corridor at an average temperature of 60° for the greater part of the winter.

The ventilation is supposed to be determined through all the cells, and up the ventilators. No distinct provision is made for the admission of fresh air, or for warming it as it enters, or for any moving power to direct the air through the flues. The action of such a system, when it acts at all, will probably be, that the air near the ceiling, and consequently in the upper story of cells, will be very warm, and the lower story uncomfortably cold. Another and not less unfortunate point in the working of this system must be this : when the doors and windows are closed, as they are in cold weather, and the air in the corridor is heated, it will rise to the top and escape through the ventilating flues into the attic or common chimneys ; but, instead of escaping into the atmosphere, a part may be drawn down through the other flues, which communicate with the lower range of cells, and again find its way through these cells into the corridor, to supply the partial vacuum which has been there produced.

In the summer season, it is understood, that, practically, this system of ventilation, if such it can be called, is, as we might readily imagine, utterly insufficient. During the summer months, especially in July and August, after one or two hot nights, the number of patients in the hospital is much increased. Their symptoms are a dull headache, dizziness, sometimes so great as to make them reel in attempting to walk, a sense of heaviness in the head, suffused eyes, coated tongue, loss of appetite, and a quick pulse ; to these are also added

prostration of strength and diarrhœa. These symptoms are soon removed by sleeping in the hospital, rest, and simple medical treatment.*

The difference between the theory and practice of this plan of ventilation may be seen from the following extracts. "The cells of the reformed prisons have permanent ventilators extending from the rear of the cell to the roof or upper loft. They have also doors, consisting wholly or in part of an open grate, that the pure air may have free access from the area, while the impure air escapes through the ventilator in the rear of the cell. And this area, from which the air is admitted into the cell, is ventilated, in some instances, with as many small windows as there are cell-doors ; and in others, with a sufficient number of large windows and skylights ; so that, on the whole, there are *few sleeping apartments to be found more thoroughly ventilated* than the solitary cells in the reformed prisons."†

"This mode [by flues opening at the tops of rooms] of ventilating the Auburn prisons has been too long attempted not to furnish experience in abundance of its inadequateness. It is certainly better than nothing, but

---

* These effects of deficient ventilation were first pointed out to me, while attending the hospital practice of the Massachusetts State Prison, by the surgeon, Dr. William J. Walker. The present surgeon, in his last Report, has also called the attention of the proper authorities to the deficiency of the prison in this respect.

† Eighth Report of the Board of Managers of the Prison Discipline Society, Boston, p. 97. — Compare this statement with the Report of the Surgeon of the Massachusetts State Prison, for 1846.

that is all the praise which can be justly accorded to it."*

It is said, these ventilators are so uncertain in their action, that in some of the Auburn prisons they have been closed. If this be so, it is certainly much to be regretted that those who, from their position or office, are supposed to be most interested in the improvement of prisons, instead of adopting this course, had not learned and added those simple means which science and experience have proved adequate to produce a very good degree of ventilation in prison-cells.

In the new penitentiary at Philadelphia, the same system of flues is provided for ventilation, but with some difference of arrangement. There are several holes about three inches in diameter near the floor of the cell, passing through the wall into the exercising-yard, and several small, angular flues passing off through the wall between the cell and the passage, about ten feet above the floor. The mode of heating in use is Perkins's high-pressure system, a pipe passing through each cell; some modifications have been recently made, but there is no separate moving power for ventilation.† We are not surprised to learn from the reports of the Prison Discipline Society, that "the air is confined in the cell."

We wish it to be distinctly understood that we make

* Dr. Bell's Letter to the Mayor of Boston, on a Plan for a new City Prison, p. 9.

† Report of the Pennsylvania Penitentiary for 1845, p. 36.

no objection to the system of flues. No ventilation can be carried on without a proper channel for the introduction of fresh air, and another for the removal of that which has been vitiated. The point we wish to urge is this, that it does not necessarily follow, because a cell is furnished with flues, that there is always a strong current through them, or even that they act at all. We feel confident that there are seasons in which they have no effect whatever, — in which they are utterly useless for the purpose intended. Neither would we wish to deny, that, at the time when visiters usually enter the cells of a prison on the Auburn plan, when the prisoners are at work, the *night-buckets* removed, every thing clean, and the windows opened, there may be nothing offensive to the smell. But we believe the flues have very little to do with this state of things, or in preventing an opposite state of the air in the night, when the prisoners and their buckets are in the cells, and the windows closed. Still, we would not have the flues filled up, and we should be sorry to see a prison built without them, — not for the good they have done or are now doing, but for what they may be made to do by adding to them an efficient moving power. While a prison is building, they can be constructed with very little, if any, additional expense, the saving of materials counterbalancing any little extra care in forming them. After a building is once finished, especially a prison, it is very difficult to introduce them in any place without great expense and trouble.

It is a common impression, that a room should be large to be well ventilated. It has been remarked with regard to the prison-cells, that, if they were larger, much less inconvenience would be experienced. If the remark is intended to imply that a larger room will hold more air, and will consequently require a longer time to become equally vitiated with a smaller room, it is no doubt true. But if it is meant that the larger room can be more easily ventilated, a little consideration will show that this is an error. All that is required for the most perfect system of ventilation is, that the air shall be pure, properly tempered in heat, moisture, velocity, and not a second time presented to the organs of respiration. These conditions of the atmosphere could be produced in a room containing one hundred cubic feet as well as in an Auburn cell which contains twice as many cubic feet. It is true that it cannot be accomplished by *spontaneous ventilation*, nor without an active moving power; but with such a power it can be done constantly and effectually.

Either of the two modes we have pointed out could be adopted for producing a constant and equable movement in the air of the cells. If the corridor were made tight, with double windows, or in any other way, so that no air could escape from it except through the ventilators of the cells, and this corridor were flooded with fresh air properly tempered, which we have shown can be done by a properly constructed fan, the point will be attained. It will also be equally attained by connecting

all the chimneys in one large trunk, through which the foul air may be conducted to the base of a chimney-shaft, either upon the building or upon the ground, in which there is a sufficiently powerful draught. Which of these two plans would be most advisable must depend upon circumstances.

We propose to present a full account of a model prison, and the details, so far as they relate to its warming and ventilation. It is that of the Pentonville prison, the description of which has been published in the Parliamentary Reports ; it will serve to show that one, at least, of the plans just mentioned, is perfectly practicable.

The objects of this prison and the subjects of its discipline are somewhat peculiar. Every person admitted to this prison is doomed to transportation under a first conviction, and is between the ages of eighteen and thirty-five. The imprisonment is intended as a period of probation, and is not prolonged beyond eighteen months ; an opportunity of learning those arts which will enable the convict to earn his bread is afforded him, under able instructers ; moral and religious knowledge is imparted to him. At the end of eighteen months, when a just estimate can be formed of the effect produced by the discipline on his character, he is sent to Van Diemen's Land ; there, if he has behaved well during his probation, he at once receives a ticket of leave, which is equivalent to freedom, with the certainty of abundant maintenance, the fruit of industry ; if he behave indif-

ferently, he is transported to Van Diemen's Land, there to receive a probationary pass, which will secure to him only a limited portion of his earnings, and which will impose certain galling restraints on his personal liberty ; if he behave ill, and if the discipline of the prison be ineffectual, he will be transported to Tasman's Peninsula, there to work in a probationary gang, without wages, deprived of liberty, — an abject convict.*

This prison is situated on an elevated part of Pentonville, northwest of London, and about three miles from the city proper.

The cells are thirteen feet long by seven feet wide, and nine feet high to the under side of the arched ceiling, and contain each about 820 cubic feet of space.

The window-frame is of strong cast iron, and is glazed with fluted glass ; and, in order to prevent communication between prisoners in adjoining cells, it is a fixture. Additional security is obtained by the insertion, on the outside, of two wrought-iron bars, so placed as not to intercept the light.

Each cell is fitted up with a soil-pan and trap, and a copper basin for washing, with waste-pipe, &c. The soil-pan and the parts connected with it are of strong, glazed earthen ware, which is much cleaner, cheaper, and greatly to be preferred to iron. The cells are lighted with gas.

---

* Sir James Graham's Instructions to the Commissioners for the Government of the Pentonville Prison.

Ventilation of the Cells. — The ventilation of a cell cannot fail to have a direct influence on the health of a prisoner, and it is therefore one of the most important objects connected with the construction of prisons. As there is no difficulty, and but little expense, in effecting it, on a principle which insures a uniform action, the necessary arrangements are adopted in all new prisons, and the same principle has been successfully applied in many of those which are already built. The means of warming the cells, when necessary, is another point which claims attention, and in winter is inseparably connected with ventilation.

The necessity of resorting to an artificial system for a regular supply of fresh air at all times and seasons will be apparent, when it is considered, that, with a view to prevent communication between prisoners in adjoining cells, it is necessary that the windows should be fixtures, and the doors generally closed.

The main objects to be attained may be thus stated : —

1st. The withdrawal of a stated quantity of foul air from each cell.

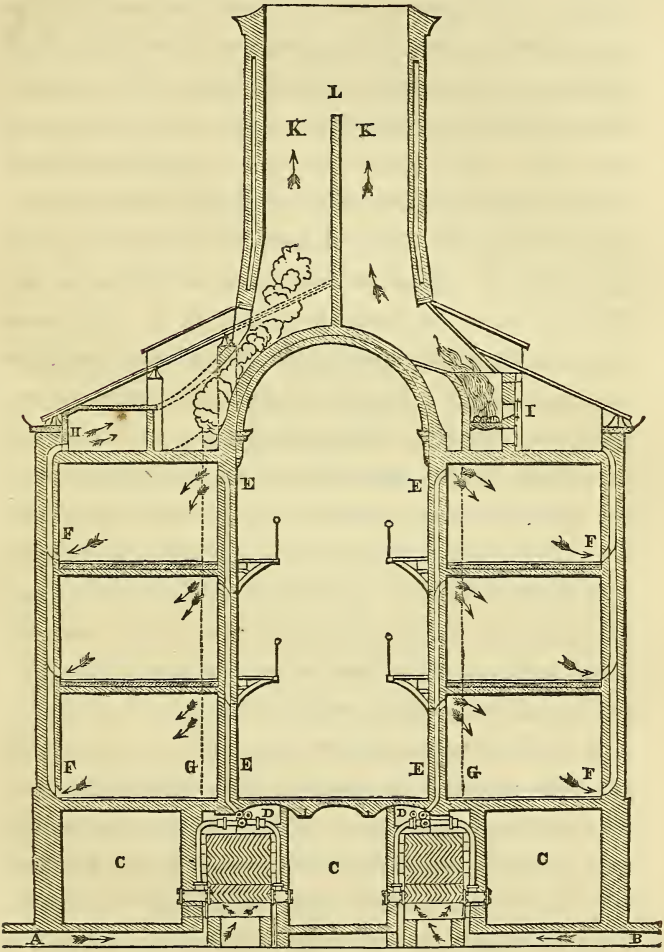
2d. The introduction of an equal quantity of fresh air into each cell, without subjecting the occupant to the prejudicial effect of a draught.

3d. The means of warming the fresh air when necessary, without injuring its qualities or affecting its hygrometrical condition.

4th. That no additional facilities for the transmission of sound should be afforded by the air-channels or flues.

The general disposition of the flues and apparatus for

Fig. 53.



effecting the several objects proposed will be best understood by referring to fig. 53.

A B, the cold-air flue, bringing air to the heating apparatus. C C C, rooms connected with the heating apparatus. D D, main fresh warm-air flue, in which are placed the flow and return pipes, seen in section. From this flue, which extends the whole length of the corridor, flues, E E E E, conduct the warm air to the top of each cell. After passing through the cell, the air finds its way into the foul-air flues, F F F F, which open at the bottom of the cell, and escapes into the main foul-air trunk, H, which extends over all the cells, and through that to the discharging-shaft, K K. L is a division in the shaft, keeping the two sides of the prison entirely separate. I is the fireplace, for producing ventilation in summer. The dotted lines, G G, indicate the position of the smoke-flues of the heating apparatus; the smoke is seen escaping into the discharging-shaft, K. The smoke and heated air produce a sufficient ventilation in winter. A fireplace, similar to that upon the right side, at I, is also placed upon the left side, but is not seen, as the section upon that side is through a plane anterior to that in which the fireplace is situated.

It will be observed, that an apparatus for warming the air, when required, is placed in the centre of the basement story of each wing. This apparatus consists of a case or boiler (fig. 54, p. 283, where it will be more fully described), to which pipes, adapted for the circulation of hot water, are attached. In connection with it, the large flue, A B, fig. 53, opens to the external atmosphere.

The fresh air introduced through this opening, after

passing over the surface of the boiler, turns right and left along a main flue, D D, which runs horizontally under the floor of the corridor, and from thence passes upwards through small flues, E E E E, preserved in the corridor wall, which terminate respectively in a grating placed close under the arched ceiling of each cell on the three stories.

A current of air may thus be introduced from the exterior into each cell ; and it is obvious that it may be warmed, or left at its natural temperature, as circumstances require.

This channel for the introduction of fresh air would, however, be of little avail in furnishing the supply required, unless corresponding arrangements were made for extracting the foul air from the cells, which, under ordinary circumstances, is the first movement that will take place. For this purpose, a grating is placed close to the floor of each cell, at F F F F, on the side next the outer wall, and diagonally opposite to the point where the fresh air is introduced. This grating, which is three feet long by six inches wide, covers an opening which leads to a flue twelve inches long by four inches wide in the outer wall, opening at its upper extremity into a horizontal foul-air flue in the roof, which communicates with a vertical shaft raised twenty or twenty-five feet above the ridge.

It will thus be seen that a communication is established, first from the outer air through the warming apparatus to the top of each cell, and thence from the

floor of each cell upwards through the extracting flues and ventilating-shaft into the outer air again. By this arrangement the total lengths of each pair of flues respectively made use of, for extracting foul air from the cells and introducing fresh air into them, are rendered nearly equal in all the stories, — thus promoting uniformity of action.

Objections may be urged against the principle of making the point of entry of the fresh air at the top of the cells, and extracting the foul air from a lower level; and, as an abstract matter of science, without reference to certain practical objections, it is certainly a question whether this order should not have been reversed.

When, however, it is considered that each cell contains 800 cubic feet of space, and is occupied by only one individual, — that a ventilation of upwards of thirty cubic feet per minute has been secured, — and that a perfect diffusion of air takes place within the cell, — it will be apparent that there is no object in sacrificing other important and practical considerations to obtain the upward movement.

It will be seen, also, that the *ascending* principle of ventilation of the entire system is preserved, and that the extraction of foul air from the cells is partly to be referred to the superior altitude of the extracting flues and shaft, which are in and above the roof. If the foul air were required to pass *downwards*, *below the floor* of the cells, into flues situated in the basement, a power must be maintained in constant operation to overcome

the tendency of air at a higher temperature to remain at a higher level. The ventilation in such a case would be entirely *forced* ; whereas, by the arrangements which have been described, it only requires to be *assisted.* From the diffusion which takes place, the difference of temperature at the ceiling and floor of a cell can scarcely be detected, and will seldom exceed one degree ; and it may be inferred that the difference of power required for extracting the air at one or other of those levels would be inappreciable. But even if it led to an increased expense in the consumption of fuel, it would be an object to secure the advantage of introducing the air at a point not easily accessible to the prisoner, and from which he would not be likely to experience any inconvenience.

Among other reasons, it may be stated that the effect of introducing the air at a low level would be, that, when the fires were not lighted, the prisoner would be sensible of the draught of cold air, and would devise some means of stopping up the grating ; and during the cold weather, when the air would be warmed, he would probably sit or lie down close to it, and be enervated by its effects.

Having thus given a brief and familiar explanation of the principle applied, and the disposition of the flues for ventilation, the application of the motive power — by which the regular abstraction of the foul air from the cells and a supply of fresh air in its place are insured — will be easily understood.

The main flues in the roof, intended for the extraction

of foul air from the cells, are connected with the vertical shaft, which appears in the section, fig. 53. During the summer months, a small fire is maintained at the bottom of this shaft, which raises the temperature of the column of air within it above that of the external atmosphere, or the general temperature of the cells, and thereby causes it to be specifically lighter. In this state it naturally rises, and the partial vacuum thus formed is filled from the adjoining foul-air flues. These main flues derive their supply directly from the cells, and the cells receive through the proper channels a corresponding supply of fresh air to replace the foul air which has been abstracted by the vertical shaft.

The quantity of foul air withdrawn from the cells will mainly depend upon the degree of temperature maintained in the ventilating-shaft. Under ordinary circumstances, if an average difference of from 5° to 10° above the external temperature be maintained, it will be found sufficient to produce the desired effect. The consumption of fuel for this purpose in the Pentonville prison has been about one hundred weight *per diem* for one wing, containing 130 cells, it having been the practice to light the fire, of which there is one on each side of the corridor, on alternate days. The cost of effecting the summer ventilation, at the present price of fuel, has been about twenty-eight cents *per diem*, or less than one quarter of a cent for each cell. During the winter months, when the fires are lighted in the apparatus below, the smoke and disposable heat, being thrown into

the ventilating-shaft above the upper cells, are found sufficient to secure an effective ventilation, and no further trouble or expense is necessary.

In the foregoing explanation it has been assumed that the atmosphere is stagnant, and no allowance has been made for the advantage derived from the pressure of the air at the point where it enters the flues, which, even in a moderate breeze, has a very favorable influence in producing a more active circulation. This additional force, though it cannot, of course, always be depended on for producing ventilation, will greatly assist it, and the action of a very moderate fire will, under any circumstances, insure it.

Warming. — In all cases in which it may be necessary to warm the fresh air required to be supplied to an inhabited room or cell, it is essential to health that the increased temperature should be derived from a moderately heated surface ; hence the advantage of using water as a medium of heating. In a hot-water apparatus of ordinary construction, the temperature of the surfaces, when exposed to a current of air, will never reach the boiling point ; and it is obvious that they may be regulated in any lower degree that is likely to be practically useful.

An apparatus of this kind is, therefore, to be preferred to any of the stoves in general use in this country, though for certain purposes the latter may be made available, and the difference of expense occasionally makes it an object to use them. They cannot, howev-

er, be recommended for cells designed for separate confinement for long periods.

The conditions prescribed for a warming apparatus for Pentonville Prison were as follows : —

1st. That the entire radiating surface should derive its temperature from the circulation of hot water, and that it should be of such an area as would maintain a temperature of 60° in the cells, when the external atmosphere was at 32° ; further, that, under ordinary circumstances, the temperature of the heating surface should not range above 100° to 120° of Fahrenheit.

2d. That there should be provision made for increasing the area of the radiating surface in the main flues in proportion as its temperature might be lowered by an increased distance from the boiler, in order to preserve an equality of temperature in those cells farthest from the central point.

3d. The means of reducing the quantity of radiating surfaces in the main flues to meet the effects of any rise in the temperature of the external atmosphere.

4th. That it should be simple in its construction, and in all the arrangements connected with it, and with the ventilation ; in order that a laborer or any servant of the prison might be competent to take charge of its management.

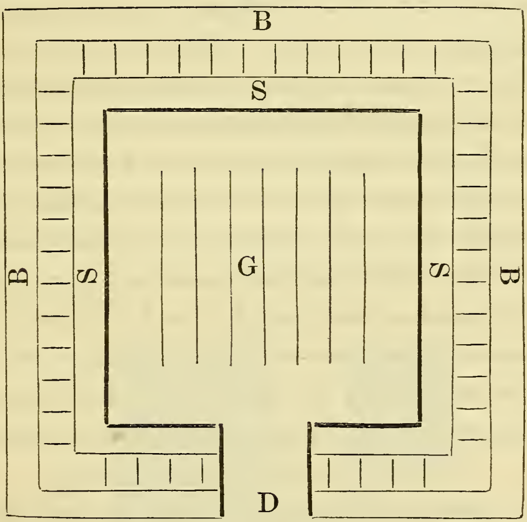
The general form and disposition of the apparatus may be seen in the section, fig. 53, and plan, fig. 54. It may be briefly described as a double iron case, of a size suited to circumstances. The space between the two

cases is filled with water and becomes the boiler; the fire is lighted in the interior, but is not brought in contact with the sides or top.

From the top of this boiler a rising main communicates in the usual way with any number of pipes that may be required, and the return pipes are introduced at the bottom.

The external case of the boiler is of cast iron, and is covered with vertical plates, about seven inches deep

Fig. 54.



and three eighths of an inch thick, placed about five inches apart, and disposed in zigzag lines over the whole surface. The preceding diagram, fig. 54, is a horizontal section of the boiler, &c., through the grate. B B B represents the brick-work of the air-chamber;

S S S, the water-space forming the boiler. Between these are the vertical plates. G is the grate, and D, the fire-door.

When the apparatus is set in brick-work, these plates occupy the interior of the air-flue which surrounds the boiler, and they serve several useful purposes : they become part of the radiating surface ; more of the air circulating through them is brought in contact with heated surfaces ; and being cast upon the outer case of the boiler, and deriving their temperature from it, the general temperature of the whole apparatus is lowered in consequence.

When it is found necessary to reduce the temperature within the prison, the circulation of water within the pipes which are disposed in the main flues may be cut off by a slide valve placed in the main, leading to the flow pipe. The only radiating surface then available would be that which has been described in the fresh-air flue in connection with the boiler ; and from the fire being placed in the interior of a large open case, and not being in contact with the sides, there is no difficulty in maintaining the surface at a very moderate degree of heat.

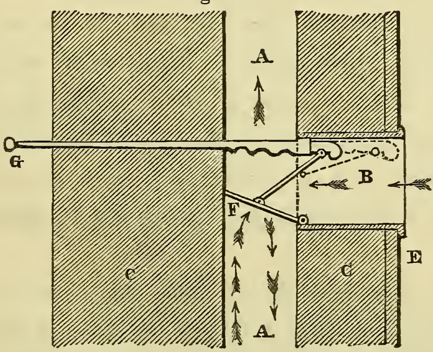
The arrangements which have been in operation for ventilating and warming the cells, and maintaining an equable general temperature within the prison, have been attended with complete success, and it only remains to explain the mode in which a prisoner may have it in his own power, in special cases, to regulate the

temperature of his cell, when artificially heated, without affecting the amount of ventilation.

The experience hitherto gained would lead to the conclusion, that, if a temperature varying between 52° and 60° be maintained during the winter months, there will be about one or two per cent. of the prisoners, who, from constitutional habit, or other physical causes, would be benefited by a temperature a few degrees above or below the average. And again, there are certain trades or employments carried on in the cells, inducing more physical exertion than others, which may also require to be specially provided for, the proportion varying with circumstances.

To meet such cases, regulators have been fixed in the fresh-air flues of a small proportion of the cells, which enable a prisoner to admit warm air from the main flue, or cool air from the corridor, at pleasure, or to mix the two in any proportion that may be found suited to his case.

Fig. 55.



The details of a regulator for this purpose may be

seen in fig. 55. A A, warm-air flue; B, opening in wall, by which cold air may enter from corridor; C C, walls between cell and corridor; F, valve, represented as entirely closing the warm-air flue; when the cold-air passage is closed, this valve assumes the position of the dotted line; G, handle in the cell, at the command of the prisoner, who can admit warm air from the flue, or cold air from the corridor, at pleasure. The opening into the corridor is of the same dimensions as those of the warm-air flue, twelve by six inches.

It has not hitherto been found necessary to provide regulators, except in a small number of cells; as, however, they will cause but a trifling addition to the expense in any new prison, and will render all the cells equally available for any prisoner or any kind of employment, it is recommended that they should be adopted.

By maintaining in the main flues a degree of heat calculated to produce the *maximum* effect required, a prisoner would have the power of keeping his cell at any temperature between that limit and the temperature of the corridor, which can be so regulated as to produce a *minimum* effect. About 5° or 6° will be found a sufficient range to embrace all the special cases which have been referred to; and it is only in such cases that any alteration in the original adjustment will be found necessary.

A few cells immediately over the steam boilers in the kitchen, and those adjoining the flues of the apparatus, required a special provision for keeping them at

the same general temperature as the others ; and it has been effected by placing a ventilator in one or more

Fig. 56.

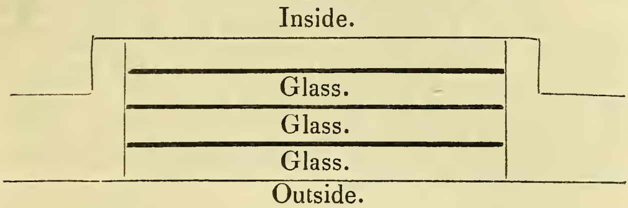
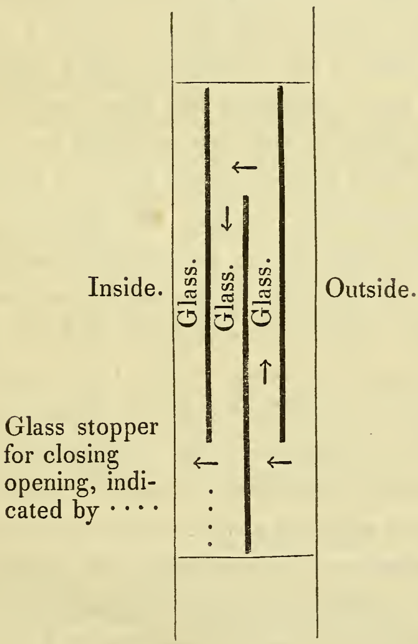


Fig. 57.



squares of the window. It was a great object to prevent the transmission of sound, and to leave the regula-

tion of the opening at the command of the prisoner. The contrivance adopted was found to answer the purpose, and is detailed in figs. 56 and 57 ; 56 being a vertical, and 57 a horizontal, section of the triple glass window. The glass stopper indicated in the section is movable, and can be made either horizontal or vertical by turning on pivots in the upper edge ; when vertical, it entirely closes the opening.

It is said, the experiments made on the hygrometric state of the cells have indicated, that, in consequence of the radiating surfaces being kept at so low a temperature,* no change of any consequence takes place in the condition of the air introduced into them ; and the means that were prepared for restoring artificially any moisture which might have been abstracted from the atmosphere have not, therefore, been applied. We do not see, however, that any diminution in the amount of moisture in the air can be produced by heating it ; nor that any more moisture would exist in air which had been heated to 100° only, and then cooled to 60°, than in that which had been heated to 200° and cooled to the same temperature of 60°. Air saturated at 60° and afterwards heated to 200° will still be saturated when again cooled to 60°. As it is a great object to preserve the utmost simplicity in the arrangements for ventilating and warming the cells, and, if possible, to confine the management to the act of attending the fires, all contrivances for meeting

* The general temperature of the radiating surfaces in the main flues has varied from 75° to 90°.

possible events and contingencies have purposely been omitted, and, as far as present experience extends, every object which is really essential has been attained.

A series of experiments has been carried on, at the request of the Commissioners for the government of the prison, by Dr. Owen Rees, the principal medical officer of the establishment, by which the subjoined facts are established.

1st. That from thirty to forty-five cubic feet of pure fresh air is made to pass into every cell in a minute; and that this amount of ventilation is maintained with extraordinary regularity.

2d. That this abundant ventilation, and a temperature ranging from 52° to 60°, can be uniformly maintained in the cells, during the coldest weather, at an expense of less than a farthing a cell for twenty-four hours.*

3d. That the same degree of ventilation is effected during the summer months at less than half that expense.

The following tables, extracted from Dr. Rees's report to the Commissioners, show the equality of the temperature within the cells, and the adjusting power of

* In the coldest weather of the winter 1842–3, the quantity of fuel consumed at Pentonville Prison was from two to two and one half cwt. for each apparatus in twenty-four hours, by which sixty-six cells and the adjacent corridors were warmed and ventilated; but in 1843–4, in consequence of the flues being quite dry, the consumption of fuel was only one half the abovenamed quantity, and the cost of warming and ventilating each cell amounted to less than one farthing for twenty-four hours; the price of coal in each case being 25*s.* 6*d.* per ton.

the apparatus and flues in retaining that equality independent of sudden changes in the external atmosphere.

No. I.

Table of recorded Temperatures for the Month of February, 1844.

Date.	External Temperature.		Internal Temperature.	
	Maximum.	Minimum.	Maximum.	Minimum.
1844, February 1	39°	28°	59°	56°
" " 2	36	28	59	54
" " 3	34	28	56	51
" " 4	36	27	55	51
" " 5	36	28	55	51
" " 6	35	25	55	50
" " 7	40	29	54	50
" " 8	42	32	54	51
" " 9	41	31	55	51
" " 10	40	32	55	51
" " 11	39	31	55	51
" " 12	36	30	55	50
" " 13	35	24	54	50
" " 14	31	24	53	49
" " 15	39	28	53	49
" " 16	45	32	53	50
" " 17	46	34	54	50
" " 18	47	37	55	50
" " 19	46	40	56	51
" " 20	47	30	57	52
" " 21	38	28	55	52
" " 22	37	31	55	51
" " 23	35	25	55	50
" " 24	49	28	54	50
" " 25	43	34	54	51
" " 26	49	39	55	51
" " 27	44	27	56	51
" " 28	38	29	54	51
" " 29	46	33	55	51

No. II.

Date.	Minimum Temperature of external Air.	Minimum Temperature of the Cells.
1844, January 1	33°	60°
" " 2	31	60
" " 3	22	57
" " 4	23	57
" " 5	42	57
" " 6	46	58
" " 7	39	60

In the record for January it will be observed, that, on the third and fourth of the month, the minimum temperature of the external atmosphere was 22° and 23°, and the minimum temperature of the cells 57°. On the fifth and sixth, the external thermometer rose to 42° and 46°, and the cells were at 57° and 58°, showing a rise in the external temperature of 24°, which affected the cells only 1°.

The power of self-adjustment is chiefly due to the nonconducting nature of the materials of which the main flues are constructed. In consequence of the pipes for radiating heat being advantageously disposed in these flues, the mass of brick-work becomes gradually heated to a moderate degree, and imparts a genial warmth to the current of air passing over the large extent of surface which it presents.

It will be apparent, from a consideration of these circumstances, that, independently of the protection against the vicissitudes of the climate derived by a prisoner, there is another important object secured by the uniformity of temperature maintained by these means. It protects him against the effects of the neglect of the person to whose charge the warming and ventilation of the prison may be intrusted; for, the quantity of fuel for producing the required temperature being determined, the management of the apparatus may be safely intrusted to a subordinate officer, who, if required to exercise in the least degree his own discretion, would be almost certain to make mistakes that would lead to inconvenience.

In the course of the experiments made, on the first occupation of the prison, in order to ascertain the power of the apparatus, it required ten days or a fortnight to produce any material influence on the general temperature ; but when the proper degree of warmth had been once acquired, and the time and quantity of coal to produce the effect had been ascertained, no further difficulty was experienced, nor can any be now anticipated.*

The fires are visited at stated hours, a certain quantity of fuel, depending on the season, is supplied on each occasion, and there is nothing more connected with the ventilation and warming to be attended to by the person in charge.

In the foregoing account of the English model prison, we have followed strictly the Report made to Parliament after it had been in operation two years. We cannot, therefore, doubt that the arrangements will continue to answer the purpose intended ; neither have we any doubt that the same plan would be found equally successful in New England, with some slight modifications. Those which will probably be found most desirable are in the heating apparatus. The changes in temperature are greater and more sudden in New England than in England or the Canadas, and we should find it next to impossible, with an apparatus like that described, to keep the temperature of the cells within the limits

---

* These points are explained more in detail in an extract from a report by the medical officer of the prison, inserted in the Appendix to the Parliamentary Report on the Pentonville Prison, for 1844.

shown in the preceding tables. The kind of apparatus to be added is that which can be brought into action quickly, and as quickly withdrawn, leaving the regular and steady supply of heat from the hot-water pipes for all ordinary occasions. These requisites are most easily met by the use of steam. If a separate boiler, with a steam-pipe extending through the same spaces in which the hot-water pipe is placed, were provided, and situated near the first boiler, the two could be conveniently attended by the same person, and brought into action as soon as required. It may be a question with some, whether steam would not in all cases be the best vehicle for heat, instead of hot water; we regard it, however, as a sufficient and a decisive reason for the use of hot water, that the temperature should be beyond the influence of any irregularity in the attendance on the fire. By the arrangement proposed, whatever little irregularity might occur in the management of the steam-boiler, it could not affect the cells beyond a certain point; the hot-water system would, under such circumstances, prove a regulator.

As the windows are fixtures, there can be no objection to the use of double windows, or, if they are not fixtures, of making them double in winter. It is also a question, whether some substitute for a double wall, in the construction of the cells, may not be introduced without weakening the structure, and at the same time afford additional security against communication between the prisoners.

We are satisfied, from what we have seen and heard of our prisons, that the officers are not sufficiently aware of the effect of deficient ventilation upon health, or of the imperfection of the mechanical means by which ventilation is usually attempted. It is highly important that they should learn the *principles* of the art; and it is only through the influence of a knowledge of these principles that we can hope that those who have the charge of prisons will be induced to bestow upon any system the attention necessary to produce a uniform and satisfactory result.

VENTILATION OF HOSPITALS.

It is unnecessary to urge the importance of ventilation in hospitals. In former times the number of deaths from the neglect of it was so great, that it may well be doubted whether these institutions did not destroy many more lives than they saved. The works of military surgeons abound with instances showing, that, however deficient hospitals may be in what is usually judged necessary to the successful treatment of the sick and wounded, if they are well ventilated, the results are far more favorable than when this last alone is wanting, and all else abounds. It is owing to this cause that their patients have often done so well in ill constructed barns, while similar cases, in well appointed hospitals, have terminated in death.

There are some diseases which are still prevalent in hospitals, and at times make dreadful havoc, which, if

not directly produced by deficient ventilation, are certainly much aggravated by it. In some of the best conducted hospitals, a disease known under the name of *erysipelas* has attacked every patient having an open wound, and compelled the surgical officers to decline all operations with the knife. This disease has in some instances spread so rapidly, attacking all patients, both medical and surgical, that it became necessary to close the wards entirely, and submit the whole building to a thorough painting and whitewashing. Many arguments could be adduced, were this the proper place, to show that this disease is dependent, in a great measure, upon deficient ventilation ; cases could be cited of badly ventilated hospitals, in which this disease was prevalent, and in some almost constantly prevalent, from which it disappeared, either wholly or in part, immediately on the introduction of a sufficient and steady supply of fresh air. It is not to be supposed that a perfectly ventilated hospital will have less of a disease than is due to the locality in which it is placed, for, undoubtedly, many diseases are peculiar to certain places ; but it is to be presumed that the frequency of such disease may be prevented from becoming greater than is due to the locality.

When we consider the influence upon the sick of a heavy, stagnant air, vitiated by respiration, perspiration, and the various emanations, many of them peculiar to disease, we can have but little doubt that the disorder we have just mentioned, and the other complications so often observed in hospitals, are consequences of deficient ventilation.

In the ventilation of a hospital, the requisites which are to be most constantly borne in mind are these.

1. The ventilation should be constant, day and night, and throughout the whole year. If during pleasant weather in summer a proper movement of the air can be obtained by means of windows, it is well ; but a power should always be at hand, which can be applied during unpleasant or calm and sultry weather, when the former mode would be insufficient.

2. The amount of ventilation should be such that the sense of smell can detect no difference in freshness and purity between the air of the ward and the external atmosphere. This, with a properly directed current, can be obtained by giving each patient about twenty cubic feet of air per minute.

3. The air, as it rises from the lower parts of the room, should move directly upward, that the emanations from one bed may not be mingled with the air passing to another.

The arrangements by which these intentions may be best answered will depend in a great measure upon the construction of the hospital, and the class of diseases which are to be treated in it ; the insane, for instance, will require very great modifications of the system adapted to the wants of a general hospital.

General Hospitals. — In this country general hospitals receive, as patients, those suffering under any disease, whether surgical or medical, with the exception, in some instances, of contagious diseases and insanity.

In general hospitals the causes of impure air are more numerous and active than in any other buildings containing the same number of individuals. Besides providing a remedy for these, it is very important that the emanations of the sick should be prevented from diffusion through the ward, both on the score of health and the comfort of the patients. The arrangements for heat and ventilation should have particular reference to these points.

It will be found to simplify the arrangements, and render the warming and ventilating more steady and certain, to have an apparatus for each story. Upon well known principles, when two pipes lead from the same hot-air chamber to different stories, the upper apartments will receive the most, if not all the heat. When the valves are under the control of those in the apartments, in cold weather the lower story must wait until the upper is warmed to the desired temperature before the lower can receive any heat. When the heating apparatus is supplied by steam or hot water, no additional expense will be incurred from adopting the arrangement proposed, as it does not necessarily imply a greater number of fires, but merely a different distribution of the radiating apparatus.

Trunks leading from each of the hot-air chambers should be placed in the walls, in the manner already described in our remarks on ventilating other buildings, — each trunk communicating only with the particular story it is intended to supply. These trunks may be made of

wood, or, what would be better, of wood inclosing zinc trunks a little less in size, which would not only, through the influence of the air between the two, prove better non-conductors, but would not be liable to crack from shrinking. There should be at least one of these trunks for each side of the room they are intended to supply. On reaching the level of the floor of the ward, the air should find its way to the right and left into a horizontal trunk taking the place of the base or mop-board, through holes in the anterior surface of which the fresh air may escape into the ward. At least two holes for the admission of air should be provided for each bed, one beneath the bed and another at its side. These openings, to distribute the air equally, must evidently be of unequal size, enlarging as they recede from the main trunk; the rule for this enlargement is sufficiently obvious.

Besides these openings, if the ward is large, it is desirable that air should be admitted through the middle of it. This can often be effected by placing a trunk beneath the floor, communicating with a raised platform under a table; from the riser of this platform the air may be allowed to escape.

This amount of diffusion — although even this could be extended with advantage — will be found to conduce very much, not only to the health, but to the comfort, of the patients. Every patient, while in his bed, will have a gentle current of air rising from all sides towards the ceiling, effectually repelling the emanations from his neighbours.

The openings for the escape of foul air should be in the ceiling. The number of these must be determined by the size and form of the ward; there is no necessity, however, for their being as numerous as those for the admission of air; two or three will, in most cases, be sufficient. Trunks may lead from these, in the space between the ceiling and floor of the room above, entirely concealed between the joists, to the side of the room, by which it can descend to the moving power, if upon the ground.

The ventilation of the water-closets should receive especial attention. Those only who have been conversant with hospitals are aware how important it is that a constant current into the closet should be established. The convenience of the patients requires that these offices should be as near the wards as possible, and any mismanagement of them will be perceived in all the wards connected with them. We shall have occasion, in a subsequent chapter, to describe the kinds of apparatus which are found to answer best. It will be sufficient to say here, that the current of air should pass from the ward into the closet, and *through* the seat, on its way to the exit-flue. This is a very simple, and experience has shown it to be a very effectual, mode of preventing any emanations from the soil-pan. It is often a great convenience to those patients who may be able to sit by their bed-sides, and yet not able to leave the ward, to have a movable close-stool. All odor from this may be prevented by placing a small exit-tube

behind the ceiling, about two feet from the floor, passing around the room horizontally, and communicating with the chimney, or other flue, in which there is a strong draught. At the side of each bed should be a smaller tube, joined to the first at a right angle, and opening into the room through the plastering ; against this can be placed a corresponding tube in a properly constructed stool, all effluvia from which will then pass off by the tube. Those tubes which are not in use should be closed.

Unquestionably, the moving power for the ventilation of a hospital should be heat in a chimney-shaft ; no other moving power is so constant and equal in its action. In the construction of a hospital, or in making additions to one already constructed, this should always be borne in mind. Where, however, the buildings are already constructed, and are furnished with exit-flues opening into the attic, great advantage would be derived from the use of a fan driven at a proper speed. The point at which it can be applied with the greatest ease will be found to be in the trunk supplying the various heating apparatuses with cold air. The resistance offered by small flues, when air is thus propelled, will be found to be very considerable ; much greater than is generally supposed.

Whether the ventilating-chimney should be upon the building, with the fire at the level of the highest ventilating openings, — that is, just above the ceiling of the upper story, — or whether it should be upon the ground, must depend upon circumstances. Bringing air down to the

ground will always be attended with some loss, and will always require forced ventilation, unless a double set of flues be provided; if it ascend directly, it will require, for an economical use of fuel, a tower or chimney at least twenty-five feet above the top of the building, which will usually give a column of heated air about thirty-five feet in length. With the latter, the ventilation will be assisted, and not necessarily always forced. In constructing a building, the ascending plan can be adopted with great advantage; in old buildings, it will be found better to bring the vitiated air to the ground, both on account of the security of the foundations and protection against fire; the symmetry of the building, also, will often make it advisable.

Ventilating-flues are frequently carried up in contact with a chimney containing a fire, that the air in the flue may receive the heat transmitted by the chimney. This, under some circumstances, may be advantageous (see page 259); but, in constructing a building, it cannot be considered as the best mode. The quantity of materials, and consequently the space occupied by them, will be great where the flues are numerous, and will become a serious objection. To this we may also add the increased resistance in small flues. It is true, where a chimney is used for other purposes than for ventilation, we can better command the draught in it with the flues so arranged, than where they are admitted directly into it; and it is probably such cases which have led to the adoption of this plan; but where the chimney is express-

ly intended for ventilation, it will be better to admit the air at its base from a common trunk. If the air is not admitted at the base, but at some point above it, with proper precautions the draught will be as steady and constant as it would be if carried up in a separate flue.

A room warmed by an open fire, with warm air admitted to supply the fireplace and give a genial temperature to the whole apartment, will be found exceedingly comfortable to those convalescents who are able to leave the ward. The temperature of the ward may then be such as is most agreeable to those who keep their beds. Convalescents need radiant heat and the light of a fire, when they cannot obtain the benefit of sunshine. Independently of any other circumstances, it is believed, that, after a certain period, disease disappears more rapidly, and nutrition is more active, in those who are exposed to brilliant light than in those who are deprived of it. In a large apartment at St. Petersburg, which is used for soldiers' barracks, one side of which receives the full effect of the sun, and the other faces a dark court, it is said, that, although the discipline, food, temperature, and access to air are the same on both sides, the number of cases of disease is three times greater on the shaded side than on that exposed to the sunshine.*

In the Massachusetts General Hospital, the warming and ventilating arrangements have undergone various changes. It was originally furnished with Derbyshire

* Letter to Viscount Duncannon, printed by House of Commons, April, 1838, p. 6.

furnaces and brick flues opening into each ward. After a time, fireplaces were introduced into the wards, and for this purpose chimneys, which had been omitted in the construction, were built. This change improved the state of the air, but not sufficiently to prevent the frequent recurrence of disease, which is believed to depend, in some degree, at least, upon deficient ventilation ; and additional change of air was attempted, by the removal of some of the panels of the doors, and supplying their place with blinds, through which the air could pass freely. More lately, one of the Derbyshire furnaces has been removed, and the mild hot-water apparatus adopted. From four hot-air chambers, each of which has a separate system of heating-pipes, four trunks lead the air to three wards and an entry ; these trunks enter at the floor, some giving a horizontal, and others a vertical, direction to the air as it leaves them. The foul air passes off at the floor of the wards, and escapes from the same chimney-stack that contains the smoke-flue, against which the foul-air flues are placed.

Although the quantity of air passed through the wards is very great, — compared with the number of persons in them, quite as great as can be desired, — yet it has not that freshness and freedom from a close, disagreeable odor, which we should expect. This we attribute to the fact, that the pure air gets mingled with the vitiated before it becomes cool, and descends low enough to be breathed, on its way to the outlet near the floor. All inconvenience from this cause would be obviated by the plan of

diffusion so often pointed out in the preceding pages. The inlet for the external air is at the surface of the ground, and dust finds its way into the wards ; on one occasion, we observed fine coal-dust deposited upon the floor and furniture, derived from a quantity of coal which had just been left near the inlet.

In that part of the wing which has been just built, and in the erection of which no expense has been spared to render it comfortable to the patients, a system of warming and ventilating nearly similar has been adopted.

The heating apparatus is placed in the cellar, and consists of two upright boilers, with the fireplace beneath ; each of these boilers supplies three systems of pipes with hot water. The inlet for fresh air is at the surface of the ground, and is protected by a coarse grating. From this common inlet, cold-air trunks, two feet wide by one and a half feet deep, lead to the hot-air chambers containing the system of pipes, — one trunk to each chamber. Of these hot-air chambers there are six ; five for warming the entries, wards, &c., and one for the water-closets. The hot-air flues for the two wards are one foot deep and one and a half feet wide. The wards are about fifty feet long by twenty feet wide ; in the middle of the ward is a large chimney, about eight feet by twelve, containing the hot and cold-air flues ; and those of two fireplaces, at opposite sides of the chimney, in each ward. The hot-air flues open into the wards by an inlet two feet high by one foot wide, commanded by a valve. These inlets, of which there are

two for each ward, are at the floor, and on opposite sides of the chimney just mentioned. Directly above these inlets, at the top of the ward, and in the same chimney, are the foul-air flues, of the same dimensions as the inlets, and also commanded by valves. Two other outlets are provided on the sides of the room, opening at the floor, the flues of which are one foot square each; and the fireplaces may also be used for the removal of vitiated air, the opening being at the usual place, on a level with the mantel.

The water-closets are ventilated by two flues, each one foot square, one of which opens at the bottom, and the other at the top, of the closet; the former for the admission of warm air, and the latter for the exit of the vitiated air.

These wards have not, as yet, been occupied; consequently, any expression of opinion as to the efficiency of the ventilating arrangements would be out of place. With our present notions, however, a large chimney-stack in the middle of a room would not be considered as adding to the architectural beauty of the apartment, taking away from it that appearance of spaciousness which is so agreeable to the eye, and really interfering with a free circulation of air in summer, if it is to depend for ventilation principally, as we presume it will, upon windows. It is a question, also, whether the chimney may not interfere with the light, which it is often desirable should fall directly upon the bed, for the examination of patients, or for the performance of oper-

ations for which it is not advisable to move the patient from his bed.

Asylums for the Insane. — The modifications of the ventilating arrangements of general hospitals, to adapt them to asylums for the insane, are principally those which will protect them from impurities and obstruction. Those who are not conversant with the insane can hardly realize the constant foresight required in this respect, not only with regard to air-flues, but every thing else connected with apartments and their furniture. It has not, so far as I am aware, been found practicable, generally, to admit warm air from flues opening near the floor. With some persons, in all asylums, no inconvenience would be experienced from such an arrangement, or even with open fires ; but as apartments are not usually sufficiently numerous in asylums to admit of classification to any very considerable extent, or at least with reference to this single point, it is found better to provide flues opening at such a height that they cannot be reached. When opening at the floor, some patients will lie against, and thus obstruct them, besides injuring themselves by exposing the head to a strong blast of hot air ; others will thrust pieces of paper into them, or spit into them, by which the entering air is contaminated. In the McLean Asylum, at Somerville, Mass., which was erected without provision for ventilation, and was also deficient in many respects as an institution for the insane, many experiments have been tried, as successive additions have been made, and we believe the conclu-

sion is, that it is better, in general, to admit the fresh air from flues opening at the top of the room, or at least above the heads of the patients, rather than at or near the floor.*

The exit-flues, not being subject to the same obstructions, may open wherever it may be found most proper to direct the current ; if the fresh-air flues open as just mentioned, the exit-flues must open near the floor. In both cases the flues may be protected by covering them with a coarse wire netting.

The same moving power will, of course, be required in asylums as in the general hospitals.

---

* This institution was, during about sixteen years, under the charge of my father, the late Dr. Rufus Wyman, who was elected Physician and Superintendent of the Asylum after the buildings were supposed to be completed, and nearly ready for the admission of patients. The provisions for warming and ventilating were entirely inadequate; those for the former were open fireplaces, surrounded by nursery fenders, which were secured by locks; for the latter, no flues for the admission of pure air were provided, and no exit-flues, except the chimneys. He tried many experiments in ventilating the part already constructed, and in the erection of additions each room had, for the most part, two flues connected with it, for the admission and removal of air ; those for the latter purpose terminating in the attic, whence the air escaped through cowls. These flues were made as large as the thickness of the walls would admit, about eight inches square, but were not provided with a moving power. Notwithstanding these additional buildings were probably better ventilated than any other buildings at that time in the country, my father was soon satisfied, that, although at certain times the arrangement of flues and cowls was sufficient, at other times nothing but a constant moving power could be depended upon to produce a proper change of air. This moving power has not as yet been added ; we understand, however, that the attention of the present excellent head of the institution has been for some time directed to the perfection of some plan for the purpose.

In most asylums, the bed-rooms are arranged upon one or both sides of a corridor, with one or more larger rooms connected with the same corridor, occupied by the patients during the day as a sitting-room, or *day-room.* The corridor, as thus constructed, not only affords a means of ready access to the bed-rooms, but may also be used as a promenade by those who remain within doors.

A satisfactory plan of ventilation for an asylum arranged as just indicated is as follows. The fresh air may ascend through flues opening near the ceiling of the day-room, and at the same height in the corridors, — their number and size depending upon the space which can be devoted to this object, and the amount of diffusion required. From these flues the fresh air is distributed through the rooms and corridors, and may be drawn off by other flues, opening near the floor of the day-rooms, and at similar points in each bed-room, to which the air may find access by openings over the doors, and escape into the ventilating-chimney. By this plan, it is true, the bed-rooms are ventilated from the corridors, but as both are very seldom occupied at the same time, this is, practically, no objection.*

---

* We understand that at the Vermont State Lunatic Hospital, at Brattleboro', where some additional buildings have been recently erected, ventilating-flues of all kinds have been omitted, by direction of the medical head of the institution. From this fact we should certainly infer, either that ventilation is, in his opinion, a mere whim, of no real use, that human beings require no regular supply of fresh air, or that the gentleman has devised some mode of ventilating without flues. If the former is true, his successors in office will have

At the New Jersey State Lunatic Hospital, now building, it is understood that a space in the cellar, between the walls of the corridors, is to be reserved for an air-chamber. To this chamber air is to be admitted at several points ; after coming in contact with large iron pipes, containing steam or hot water, and being sufficiently heated, it is to be conducted, by flues in the walls of the corridors, to all the rooms in each ward, and to the corridors, to which it gains admission by many orifices.

The ventilating arrangements are as follows. A large flue or air-trunk is constructed at each end of the corridors, with partitions, so that each corridor will have an ascending or descending current, as the season or the state of the atmosphere may demand. These air-trunks will terminate below in an air-drain, and this last will conduct the foul air to the fireplaces of the establishment, or, if these are inconvenient, from their distance, to fireplaces provided for burning the impure air. Above, the air-trunks will terminate in a shaft, which will form an ornamental structure over the roofs of the central and extreme pavilions ; in this shaft will be the fireplace for producing a forced ventilation, if any such shall be required. Flues will be constructed for ventilation, connected with each room and terminating in the main trunks ; the flues are to be fitted with valves. By these arrangements it will be in the power of the managers to cool the air in the chamber in summer, and dis-

---

some cause to regret his conclusion, and his patients still more ; if the latter, we congratulate him on his ingenuity.

tribute it over the house ; for this purpose a supply of water is to be provided.*

The ventilation of the new buildings of the Royal Lunatic Hospital of Charenton may be presented as indicating the plan which is now believed in France to be the best in use.

These buildings are constructed with separate rooms, two hundred in number, each having about 1,400 cubic feet of contents ; these rooms are arranged upon an open gallery or corridor, with which they all communicate. The warming apparatus consists of a boiler composed of two concentric hemispheres, placed one within the other, and the space between them filled with water. The fire is placed beneath, and, after rising into the concave surface of the boiler, encircles its exterior before it escapes into the chimney.

Two copper pipes connect this boiler with a cistern in the attic ; the first, attached to the top of the boiler, conducts the hot water immediately to the cistern, while another pipe, descending from the cistern, passes through the various apartments, warms them, and returns to the boiler, entering it at the bottom. The circulation of warm water, in consequence of a change of density, is constant. The mode of distributing heat in the rooms, and the form of the radiators, will be described in the chapters on Warming.

The air intended for the ventilation of the apartments is also warmed. Those rooms near the boiler are sup-

* Pennsylvania Journal of Prison Discipline, Vol. II., p. 59.

plied with air which has been warmed by the smoke; those at a distance have an air-channel beneath them, through which hot-water pipes pass, and effectually warm it. The air which has been warmed by the smoke enters a channel, from which it rises into each room, through a special flue constructed in the wall. The opening of this flue is about seven feet above the floor of the room. The exit-flue opens just above the floor of the room, is of the same size with the fresh-air flue, and discharges into a large foul-air channel which extends over all the rooms, and finally terminates in the ash-pit, beneath the boiler.

This plan is applied to those rooms of the hospital situated near the boiler; those more remote from it are ventilated by other means. From the cistern in the attic, a hot-water pipe (or ventilation-pipe, as it is called) descends by one of the corners of the room to be ventilated, and communicates with the bottom of the boiler. This pipe is surrounded by another and larger tube, of zinc, which again is covered by some non-conducting substance. This zinc tube has openings connecting with the apartments, as it passes near the floor; through these openings the foul air enters the zinc tube, is warmed and dilated by the hot-water pipe it contains, rises into the attic, and then escapes through proper channels. That the air escaping from one room may not interfere with that from another, the tube is divided into compartments, one for each room, by divisions extending from end to end.

The fresh air is warmed by coming in contact with the hot-water pipes in the air-channel above mentioned, and enters the room by separate flues.

In summer, when the apartments are to be ventilated only, all other pipes, except the ventilation-pipes, are closed ; the fresh air then enters at the external temperature, and passes through the rooms on its way to the exit-tube, in which a constant rarefaction is maintained.

From experiments on the amount of ventilation, it was ascertained that those rooms depending upon the fire under the boiler for producing a current were supplied with nearly forty cubic feet per minute, and those furnished with hot-water ventilation-pipes about seventy cubic feet in the same time. In the dormitories the ventilation was less active, but still sufficient. One of the members of the commission appointed to examine the ventilation of these buildings was Gay-Lussac, the distinguished chemist, who pronounced it sufficient.*

It must be observed, however, that, for reasons already stated, we cannot obtain the same regularity of ventilation, or have it under the same control, where we depend for a current upon the fire of the heating apparatus, as where a fire is provided for this special purpose.

The valves for controlling the various flues of asylums must, of course, be placed beyond the reach of the inmates. A valve in common use at the McLean Asy-

---

* Annales D'Hygiène Publique, Juil., 1844.

lum, and perhaps in other asylums, and which is found to answer well, is made as follows. A frame of cast iron, having a flange in front, is set in the flue, with the flange resting upon the face of the flue, and forming a finish to the opening. Just behind the flange, a wire netting is so secured to the frame that it cannot be removed by any ordinary means in the hands of the patients ; still farther in the opening is a piece of sheet iron of the size of the frame, hung on two pivots at its upper edge, turning in the sides of the frame, and falling down against its back when shut. The valve is moved by turning a screw, which passes through the upper side of the frame in its middle, and strikes against the valve ; as the screw is very near the centre of motion, a very small movement of it is sufficient to produce all the motion that is required in the valve. To render the movement of the valve uniform for the same number of turns of the screw, a curved piece of iron is riveted to the upper edge of the valve ; this piece of iron is concave towards the end of the screw, and consequently always presents a surface for the screw to act upon, which is at right angles to its axis. The screw is turned by means of a key, the same which fits all the locks of the house.

CHAPTER XIV.

VENTILATION OF DWELLING-HOUSES.

Ventilating Arrangements for Dwelling-houses simple and easily obtained. — Fireplaces good Ventilators. — Dimensions of the New England Fireplaces in olden Time. — Gradual Diminution of Fireplaces to present Time. — Ventilation by Stoves usually deficient. — By Hot-air Furnaces sufficient. — Requisites for Ventilation in Dwelling-houses. — Objections to a Flue opening at the Top of the Apartment; Room will not be well warmed. — If the Flue enters the Chimney, the Room will be subject to a Recoil of Smoke. — Outlet at the ordinary Height of the Mantel, or lower, sufficient. — Mr. Tredgold's Siphon. — Ventilating-flue to be provided with a Valve. — Parlour Stove fitted with Ventilating Apparatus. — Hot-air Furnaces should deliver the Air into an Apartment in a horizontal Direction. — Every Apartment should have a Fireplace or Ventilating-flue. — Best Mode of warming and ventilating a House without Regard to Expense is an Air-heating Apparatus and an open Fireplace. — Bedrooms should have Ventilating-flues. — Dr. Arnott's Machine for ventilating Dwelling-houses.

In the ventilation of dwelling-houses, the necessary apparatus is simple and easily obtained. The number occupying the apartments, compared with their size, is usually small, and the supply of air, although it should be sufficient and constant, can be proportionally reduced. The air of an apartment which is not constantly occupied may be considered as fresh air in store, for which due allowance may be made; we must also bear in mind, that much air enters when the

doors are opened, and through the crevices of the windows. The additional provisions for ventilation must depend, in a great measure, upon the mode of heating.

Common open fireplaces draw towards them a large amount of air, much greater than is required for the combustion of the fuel. The quantity of air passing off by a moderate-sized chimney with a small fire, in which about four and a half pounds of wood are consumed hourly, has been estimated to be from ten to twenty times that required for the combustion of the fuel. Such chimneys must, therefore, be considered as powerful ventilators. In some of the old houses in New England, the chimneys are still standing, having fireplaces eight feet in length by three feet deep, and a height to the mantel of nearly four feet. With these chimneys, the draught occasioned by the large quantity of wood consumed was such, that, without the *settle* to protect the back from the strong current of cold air pouring in at the doors and windows, and retain the radiant heat, it was impossible to keep comfortably warm. It would be well for those who question the importance of ventilation, because our forefathers lived to a good old age without even understanding the meaning of the word, to call to mind their fireplaces, the kind of houses they occupied, and the quantity of air which must have passed through their houses.*

* The various changes which the fireplace has undergone in one old house in Cambridge, Mass., known as the Danforth house, and said to have been built by one of the early presidents of Harvard College,

From these large, open-throated chimneys, there has been a gradual diminution, until the space for the escape of smoke, as now formed for anthracite coal grates, is seldom more than twelve or fourteen inches long by three inches wide. By these improvements, the escape of heat by the chimney has been constantly diminishing, and the amount of radiant heat, which in such fireplaces is mainly depended upon for warming, remains as great, if it is not increased ; but the ventilation has been greatly diminished, although, perhaps, not beyond what will suffice for rooms not overcrowded, if we provide proper means for admitting air.

The various forms of stoves are still more efficient in warming, since they permit the escape of nearly all the heat before the gases reach the chimney, but are quite deficient as ventilators. There are still other forms of apparatus, which heat without withdrawing from the apartment even the amount of air required to supply the fire.

Hot-air furnaces, which heat by currents of warm air, must necessarily prove good ventilators, if the same air

---

well illustrates the progress in house-warming. The fireplace in the parlour was originally eight feet wide by three feet deep, and four feet high. The first alteration was in the diminution of the fireplace (*Rumfordizing* it), by lowering the mantel to three feet and reducing its length to less than five feet, by which a good closet was secured on each side within the jambs. Within this structure was afterwards placed an iron *fire-frame*, for the combustion of wood ; and this, again, received a grate for burning anthracite coal, the front of which is now bricked up and receives the funnel of a *cooking-stove*. The improved heating and diminished ventilation are easily traced.

is not repeatedly passed through the furnace, as is sometimes attempted. In consequence of the low specific heat of atmospheric air, rooms cannot be sufficiently warmed without admitting to them more air than those occupying them will require.

In ventilating dwelling-houses, it is to be observed, —

1st. That each room fifteen feet square, for the accommodation of six or eight individuals, should have a flue for the escape of foul air, either in the chimney or elsewhere, of at least one hundred inches area. A bed-room should have an outlet of nearly the same dimensions.

2d. An inlet for fresh air should be provided for each room and bed-room.

3d. That fresh air in winter should always be moderately warmed before it is introduced into apartments.

4th. That all apertures for the admission or exit of air should be provided with valves.

5th. In summer, nearly all the ventilation will be produced by the opening of doors and windows. It is here supposed that the flues are constructed in the ordinary manner, and receive no warmth from the heat of neighbouring flues ; if such warmth is received, the draught will be proportionally increased, and the flues may be diminished.

If the heating apparatus is an open fireplace, we have an amount of ventilation going on by the chimney-flue, varying with the supply of air to the apartment, the heat of the chimney, and the direction and force of the wind.

In the old-fashioned fireplaces we have just described, the air is drawn off from a level above the heads of those seated in the room ; in the smaller fireplaces and grates in common use, this is not the case. The gases produced by respiration and combustion, which rise above the outlet, are consequently not directly removed. It has been proposed, therefore, to construct flues opening at the ceiling and reaching to the roof, or to the same height with the smoke-flue, or even with an opening into the smoke-flue itself.

This plan, although it is founded upon correct principles so far as ventilation is concerned, cannot be adopted in a cold climate without some precautions. If the only object were the removal of foul air, it would undoubtedly be effectual ; but we must warm as well as ventilate an apartment. Merely theoretical notions upon this subject will very frequently be found to fail when applied to practice. The conditions for success are so numerous and complicated, that those who have not been schooled by practice will rarely be able to devise a plan which will not require many modifications. This is especially true of double outlets in the same apartments. The flue connected with the outlet at the top of the room, even if it pass to the top of the chimney, will be subject to the draught of the chimney and the action of winds upon its summit, by which smoke may be drawn or driven into the room. Such cases have occurred, and the ventilating-flue has been closed in consequence. This evil can be remedied by providing a free supply of

air for both air and smoke-flue. But the air which enters must be warmed, or it will not be tolerated; and if it is too much warmed, as compared with the air of the room, it will rise immediately to the ceiling, and escape through the ventilator; and, not mingling with the air in the body of the room, it will thus greatly diminish or entirely prevent any change of air, where most wanted.* When the outlet at the ceiling opens into the smoke-flue, if the draught is powerful, it will, for the most part, do well with a steady wind which does not descend upon the chimney-top, a constant fire, and a free supply of air; under any other circumstances, the smoke and fire may be driven into the room, unless the aperture is provided with a valve and moved as the conditions vary. With persons who pay particular attention to the air of their apartments, valves in the smoke and air-flues could be made to answer a good purpose in obviating the evils just mentioned; but generally, after once or twice experiencing a little inconvenience from a recoil of smoke, the valve of the air-flue would be closed, that of the smoke-flue opened, and so allowed to remain. Valves are often placed in the *fire-boards* used to close the fronts of chimneys, made in the following manner. The opening for ventilation in the fire-board is covered by a piece of wire netting, behind which, and nailed to the upper edge of the opening, is hung a flap of silk of the same size as the netting; the moving of the flap allows

* See ante, p. 139.

the air to enter the chimney, but closes with any downward draught. Such valves might prevent a recoil of smoke. It may be remarked that the flue at the top of the room must be large enough to draw off the vitiated air immediately; otherwise, under the influence of the currents produced by the cold walls and windows and the cold air from without, it will mix with the air of the apartment, and be again brought down to the floor. With such a flue, we repeat, it would be exceedingly difficult with ordinary arrangements to warm the apartment.

If the fireplace be made the outlet, the air of the room may not be preserved as pure as that in a public hall provided with an elaborate system of ventilation, like that which has been described in a previous chapter; but if the supply of fresh air is sufficient, the impurity can be prevented from passing a certain point, a point far below that which it usually attains in dwelling-houses.* Practically, therefore, in apartments warmed by an open fire, the smoke-flue should be considered as the ventilating-flue; and if we consider that the velocity of smoke in a chimney with a good fire is estimated to be from three to four feet per second, we must admit that, for ordinary rooms, it will be sufficient.

Mr. Tredgold, who says that all the plans he has seen or read of, for drawing off air from the top of a room, are objectionable, either from being wholly inefficient,

* See Appendix, No. XVIII.

or from causing the chimney to smoke, proposes the following mode of effecting the object. A tube is concealed behind the plastering, or placed in a corner of the room, near the fireplace ; this tube, one end of which opens at the top of the room, descends to the hearth of the fireplace, and then turns and ascends in the chimney some little distance, where it terminates. That portion of the tube in the chimney and near the fire becomes warm, and a current is induced, which is supplied by the air from the upper part of the room.

In all cases where a ventilating-flue opens into a chimney, care must be taken that the air as it enters the chimney shall not strike across the ascending current, and also that it be protected from falling soot. The end connected with the apartment must be fitted with a valve. When an air-flue is carried to the top of the chimney-stack, it should be secured against the influence of the smoke of a neighbouring flue.

For warming the air for ventilation, we cannot expect, in private houses generally, to command a separate fire ; it must be done by that which warms the apartment. We have already * pointed out one of the modes of introducing pure warm air ; another is the double-backed fireplace. By the latter, warm air may be admitted in a diffused manner on either side of the fireplace, from a broad opening on a level with or a little above the mantel, the front of which opening may be covered by per-

---

* See ante, p. 118, fig. 15.

forated metal, and the channel conducting the warm air from the space between the two backs built of bricks and plastered. This space communicates, of course, by means of a proper trunk, with the outer air. Great care should be taken that the air-chamber of the fireplace and the smoke-flue are entirely distinct ; otherwise the smoke will be drawn into the room, or the warm air will escape into the chimney. Other modes will be described in the chapters on warming. By this arrangement, the air enters the room partly in consequence of the heat it acquires in passing through the fireplace, but more from the effect of the draught in the chimney. As it enters, it rises towards the ceiling, and afterwards gradually descends as the air below is drawn off, producing, in truth, a downward ventilation throughout the whole apartment.

Stoves may be, with little trouble, so arranged as to heat the air for ventilation, either by allowing it to pass through tubes in the body of the stove, or between the stove and a casing, or simply by allowing it to impinge upon the external surface. In either case, if the fireplace is left open, the entering air will take the course indicated in the preceding paragraph.

A parlour stove arranged in the following manner is found to answer well, both as regards ventilation and warming. The stove is placed with its back on a line with the front of the fireplace, the throat of the chimney closed, and the smoke-pipe passed into the chimney below the mantel. Fresh air, which is intro-

duced through the back of the fireplace by an opening about ten inches square, passes by the stove, and is warmed by it on its way into the room. The exit-flue, a sheet-iron tube, is connected by its upper extremity with the chimney at the throat, and by the lower with an opening on a level with the hearth, and a little in front of the fireplace ; one of these tubes is placed on each side of the stove. The room, which is large, is very equably warmed, and the air is in a good state.

Where the apartments are warmed by heated air, unless its temperature is much greater than is consistent with purity, the ventilation is sufficient. The register for the admission of the air should, however, be differently placed from those in common use. When in the floor, the current is directly upward, with very little tendency to diffusion, consequently imparting no heat directly to those standing or sitting around it. There are also other objections ; in sweeping the floor, dust frequently falls into the flue ; when the register is left open, dirt falls from the boots of those who are warming their feet or walking over it. The diffusion will be increased, and the other objections obviated, by admitting the air horizontally, from an opening in the base, on a level with, or just above, the floor. The objection might be brought against this mode of introduction, that the timbers are frequently placed under the partitions and project beyond them on both sides. This objection could be removed by flattening the flue, and removing a portion of the upper edge of the timber in an oblique direction ; the

opening in the room will then be increased in length and diminished in breadth, a change of form which increases the diffusion of the heated air.

An apartment warmed by a hot-air furnace requires a chimney or other flue by which air may escape. We should consider it unnecessary to mention this, were it not that many houses have been constructed, of late, without flues, under the impression that they were for no other purpose than the removal of smoke, and consequently not needed in a house warmed by heated air. Even if they were not required for ventilation, they are essential in warming ; for no air can enter a room unless an equal quantity escapes. As a general rule, every apartment should have a fireplace of some kind, not only for the sake of its flue, but also as a substitute for the heating apparatus, in case of accident, or when it may be undergoing repairs.

The three modes of warming now described include all those in common use. There are some other modes in which the apparatus is placed in the apartments and warms by radiation, not necessarily requiring any change of air whatever ; these may be made to warm the entering air in one of the ways described for stoves, or others analagous to them.

If we would have the pleasantest mode of warming and ventilating a dwelling-house, without regard to the trouble or expense, we should certainly combine the open fireplace with an air-heating apparatus, which should never exceed in temperature 212°. The first is

desirable for its pleasant light and radiant heat, while the second gives to the entries and chambers a mild atmosphere, which prevents cold draughts from open doors, and at the same time, through an opening in each apartment, moderately warms it, and likewise supplies air for the ventilation going on by the fireplace. The fireplace, also, has its influence upon the introduction of the warmed air. The heat of the chimney establishes a current, which draws from the air-heating apparatus a large supply of air, of a lower temperature than would otherwise enter the apartment. We know of no single apparatus which warms and ventilates a dwelling-house in so healthy and comfortable a manner as is accomplished by this combination.

Bedrooms are often entirely deficient in means of ventilation. They are frequently small rooms, at a distance from a chimney, used only as sleeping apartments, and therefore thought to require no fireplace. If we would be convinced of the importance of ventilation in these rooms, we have but to enter them in the morning before the occupant has left his bed; the air is often offensive in the extreme, even when the occupant himself is entirely unaware of any departure from the healthy standard.*

* The following fact may be mentioned to show the influence of ventilation of sleeping apartments on disease. Near Glasgow, a long building was erected for the accommodation of the operatives in factories; the rooms were placed on one side of a corridor, into which they opened. These rooms were often crowded with persons who were careless of cleanliness and ventilation, and who in consequence

If a bedroom have a fireplace, and a sufficient opening be left over a door communicating with an entry, or a proper flue be constructed, communicating with the external atmosphere, sufficient ventilation will, in most cases, be obtained. If there is no fireplace, a tube leading through the roof, or, what is better, to a chimney having a sufficient draught, will be required, in addition to the same provisions for the admission of air.

During the summer, much more air will frequently be required in our dwelling-houses than can be obtained through any openings which will be provided for this special purpose. Under such circumstances, we must depend upon windows and doors. For this purpose, windows, both sashes of which are movable, will be found of great practical value. By regulating the two openings, we can obtain a much more extensive and satisfactory movement of the air than can be obtained by a single opening, however well situated.

We have made no mention of mechanical power for ventilating dwelling-houses, because we have not considered it usually applicable. Others have thought differently. Dr. Neill Arnott has described a machine for this

---

suffered severely from frequent visitations of malignant typhus. Mr. Houldsworth, the proprietor, placed a pipe in the corridor, communicating by a branch with each sleeping-room, just over the bedstead, and terminating in the great chimney of the mill. When the steam-engine is stopped (and it is then only that the operatives are in their rooms), the corridor pipe is opened, and a current rushes in from every apartment. From this time fever disappeared, and the habitations have become remarkably healthy.

purpose, in the Minutes of Evidence taken before Commissioners of Inquiry into the State of Large Towns and Populous Districts, July 8th, 1843. Dr. Arnott there says, a pumping apparatus, to be worked by one man, might be easily made to perform the office which a force of from forty to eighty men would accomplish with common, defective machinery. The mode in which he proposes to accomplish this is, to "allow the air to pass through wide openings, so that a very gentle force or pressure suffices, and which may be exerted with a comparatively light piston, with valves of cloth, merely, in the form of curtains, resting against wire-net supports, instead of heavy flaps of wood or metal. Such construction removes the whole objection arising from expenditure of power." Dr. Arnott goes on to remark: — "I may illustrate the subject of this pump, by supposing a passage or lobby to exist, ten feet square and fifty feet long, through a house. This passage would hold 5,000 cubic feet of air. If a little go-cart were placed in it, with a sail hoisted on it, to fill the passage nearly as a piston fills a barrel, the passage being open at both ends, and there being no wind, a child would, in pushing his go-cart from the one end to the other, discharge 5,000 cubic feet at one end of the passage, and would draw in as much at the other, without knowing he was doing any thing but moving his cart forward in an empty space; and if the passage opened directly into a large apartment, by a door as wide as itself, the action of the go-cart would evidently change, at each turn, 5,000

cubic feet of air in that apartment. If, however, instead of having the end of the passage quite open, a hole were left in it of only one foot in diameter, then, evidently, the air would have to pass out by that hole one hundred times as fast as the sail of the go-cart was moving, and it would then require one hundred times the force to carry the sail forward at the same rate to expel the air. And if, farther, the air had to enter the passage by an equally narrow opening, the force required to move the go-cart would be again doubled. With large openings at both ends, very slight force suffices, because then the whole work to be done is not to lift any weight, but merely to overcome slowly the inertia of a certain bulk of light, aerial fluid, nearly as is done by a person who pushes an expanded umbrella before him on a calm day." He conceives that this machine could be constructed very cheaply, and could be put in motion by a weight, which could be wound up at stated times like a clock, if it were wanted for an evening party ; or motion could be given to it by the water flowing from a main into a cistern at the top of the house, and acting like the weight as it descended.

If air could be thus easily put in motion, it would certainly very much diminish the power required for ventilation, and neither the fortieth nor the eightieth part of the force now used would be needed. But, although there is no weight to be raised, and air is a light, aerial fluid, it offers a very sensible resistance to bodies moving through it, and requires a very sensible power to

force it through channels, even when much larger than those usually provided for it. A consideration of the following well established principles in hydraulics will place this machine in its proper light. 1. The resistance offered to air is proportional to the length of the canal through which it passes. 2. The resistance increases in proportion to the square of the velocity. 3. The resistance is in the inverse ratio of the diameter of the canal.

We see, then, that where the hole has an area of but one foot, and the air moves one hundred times as fast as before, the force required is not merely one hundred times as great as before, but it must be increased as the square of this velocity ; further, this increase of force must, upon the principle of the hydrostatic bellows, be expended, not upon the whole sail, but upon each square foot of the sail ; results widely different from those above stated by Dr. Arnott. Air must meet with resistance in passing through the heating apparatus and air-channels ; and this resistance will not be annihilated, even by making the sum of the areas of the channels equal to the area of the sail, for it is a very different thing passing air through one hundred holes of one foot area, and passing it through one hole of a hundred feet area ; and yet, in practice, it is the first rather than the second condition that we most frequently meet with. To overcome resistance, power must be expended, whether developed by heat, or applied through machines. We would not say that an apparatus of this kind might

not be used for ventilation, but we believe that the inference naturally drawn from Dr. Arnott's statement would be very far from the truth ; we have even heard it proposed to use the power of a smoke-jack to move the valve back and forth, and apply it to the ventilation of a large building.

A machine has been for some time in use in India for ventilating and cooling dwelling-houses, called a *Thermantidote.* It is made like a common winnowing-machine, placed upon wheels, that it may be moved to any part of the building. The air, as it enters the central openings, is cooled by being drawn through a coarse matting kept constantly wet with water dripping from a reservoir at the top of the machine. From the opening in the circumference the air is thrown into the apartment where it is desired. It is said to answer a good purpose, but requires two men to keep it in motion for more than half an hour at a time.

CHAPTER XV.

VENTILATION OF SHIPS.

Condition of the Air in Ships often much worse than that of badly ventilated Dwelling-houses. — Sailors often subjected to sudden Changes of Temperature from imperfect Ventilation. — Wind-sail; useless in calm Weather and in stormy Weather. — Exhausting Conical Cowl; no more useful than Wind-sail, and more cumbersome. — Ventilation by Fire; rejected on account of Danger. — Dr. Desaguliers's Fan. — Dr. Hales's Bellows. — Ventilation in British Navy. — Plans tried in American Navy. — Great Obstacles to Ventilation of Ships, Want of Room for Air-channels and Moving Power. — Plan for Ventilation. — Air-passages already exist in large Vessels. — Ventilation of Steamboats.

Those who have had opportunities for examining the condition of large ships of war at sea describe the state of the air at night, when the men are in their berths, and the ports closed, as heavy and unpleasant, far beyond what we are accustomed to observe in poorly ventilated houses. The condition of the smaller vessels is said to be very much worse than that of the ships of the line, from the fact that there are no apertures in their sides except the air-ports, and these can be opened only in a smooth sea. In neither class of vessels are the port-holes on the berth-decks or the air-ports open during the night.

The position of the hammock in which the sailor

sleeps renders ventilation of great importance. The hammocks are drawn up closely to the under side of the deck, and are consequently enveloped in the products of respiration ; they are also sometimes arranged so closely that little air can pass up towards the under side of the deck and reach the face ; most of the fresh air must, consequently, enter at the ends. The principal openings by which air enters when the ports are shut are the hatchways ; these are more or less open, according to the size of the ship and the state of the weather. Between these openings a current is usually passing, its direction governed by that of the wind, or some accidental causes, and therefore liable to change. By the necessary delay in trimming wind-sails after a change of the ship's course, the principal current of air may be reversed, and those who have been in a cool, fresh air, from their proximity to the hatchway at which the air enters, may suddenly find themselves breathing a hot, moist atmosphere, loaded with the exhalations of those by whom it has passed ; while those who were near the hatches serving as an exit-flue are as suddenly exposed to a chilling blast, and the dangers consequent upon a checked perspiration.

The machine principally depended upon for the introduction of fresh air is the *wind-sail*, which consists, essentially, of a tube of canvass, of various diameters, according to the amount of air it is intended to deliver, the upper extremity of which is flared out on either side to catch the wind and direct it down the tube. It is ob-

vious, that, however valuable an assistant the wind-sail may be in the ventilation of a vessel, it can be of no use in calm weather, nor in bad weather, when the hatches are battened down, and when ventilation is most wanted. It is also equally obvious, that, when it is used to air any particular portion of a ship, there is danger that it will drive the foul air to other parts, instead of removing it directly.

Another ventilator has, in several instances, been introduced on board of United States ships. It consists of a tube of canvass, upon the top of which is a cowl, with its mouth turned from the wind. This has been in some instances made of a conical form, that the wind, in sweeping over it, may tend to exhaust the air from the tube, and this last is stiffened by means of hoops, to prevent its collapsing. It has, however, been rejected, because it did not fulfil practically the purpose for which it was intended, and on account of its bulk and liability to derangement.

Several other modes of ventilating ships have been suggested at different times, and used with more or less success. In the English navy, about one hundred years ago, it was proposed to make use of the fire by which the provisions of the ship's company are cooked to produce a ventilating current.* Pipes were led from the ash-pit to those parts of the vessel in which change of

---

* Great benefit is derived, in the United States ships, from the current of air which is produced by placing the galley on the berth-deck.

air was most important, and through these it was supposed a constant draught would be induced, causing a corresponding influx of pure air. This plan was, however, soon abandoned, as it was found that the smoke and flame were in some cases driven by a sudden gust of wind through the pipes into the ship. Within a few months, a somewhat similar plan, with the addition of pipes for the admission of fresh air, and of a fire for the special purpose of ventilation, has been proposed for the French navy.* But the burning of a ship at sea is so dreadful a calamity, that no means of ventilation will be for any length of time persevered in, which is in any degree hazardous in this respect.

About the year 1740, two modes of mechanical ventilation were introduced into the British navy, the first by Dr. Desaguliers, and the second by Dr. Hales. Dr. Desaguliers used for this purpose the fan which we have already described as having been employed for the ventilation of the House of Commons. This he placed in any part of the vessel which was most convenient, and, by means of a tube connected with the part of the vessel to be ventilated, either threw in fresh air, or withdrew that which had been contaminated.† Dr. Hales's machine was contrived to act on the same principle as a

---

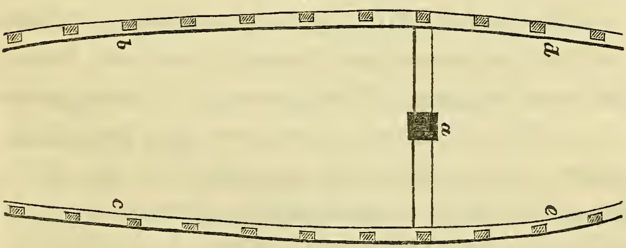
* Comptes Rendus des Séances de l'Académie des Sciences. 29 Décembre, 1845.

† Dr. Desaguliers's machine has been reproduced lately by Mr. Espy, for the ventilation of merchant-vessels, with what success we have not learned.

pair of common bellows, and was used only for pumping air into the ship. Neither of these plans were in use long, and after a time seem to have been entirely forgotten. More recently, Dr. Reid has revived Dr. Desaguliers's plan, modifying it and adding proper channels for the introduction of fresh air. His plan may be described briefly as follows. In the hold, just beneath the deck, and running fore and aft the vessel, two air-trunks are placed. These air-trunks, of which there is one on each side, are fixed against the planking of the vessel, and communicate, by means of upright trunks, with the upper part of each deck to be ventilated. A fan or other mechanical power is then placed upon a common discharging-shaft, connected by transverse trunks with the fore and aft trunks in the hold. This discharging-shaft is placed in any hatch where it can most conveniently be done.

The following figures are intended to illustrate the application of this plan to the Minden, a ship in the British navy. Fig. 58 is a plan in which *b d*, *c e*, represent

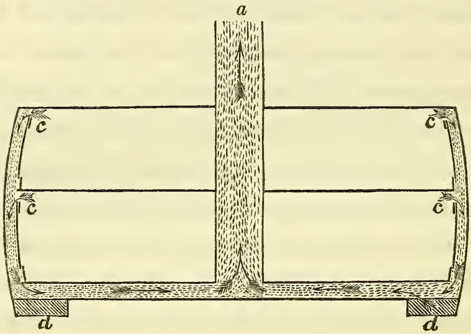
Fig. 58.



the trunks in the hold, running fore and aft the ship ; the

square shaded marks represent the perpendicular air-trunks reaching from the horizontal trunks, *b d*, *c e*, to the different decks above. *a*, the discharging-shaft, connected by the two transverse trunks, one on either side, with the horizontal trunk. Fig. 59 is a transverse sec-

Fig. 59.



tion through the discharging-shaft, *a*. *c c c c* are the vertical trunks communicating with the horizontal trunks, *d d*, at the bottom, and these last are connected by the transverse channels with the discharging-shaft, *a*. The vertical trunks are fitted with valves, as represented in the section.

In the United States navy, some attempts have been made to introduce a better system of ventilation, but not with much success. A few years ago, at the suggestion of an officer of the navy, tubes about three inches in diameter were placed in the gun-deck of a ship of the line, and opening a communication between this deck and the orlop-deck beneath. The orlop-deck is the lowest deck, and beneath it is the hold; upon this deck

are state-rooms for several of the officers, and, as it has no ports or other openings in the side, it is often exceedingly uncomfortable for want of fresh air. It was supposed that the short tubes above mentioned, of which there was one in each state-room, would produce an important change in the air of these apartments. Their action was found to be unsatisfactory, as might have been anticipated ; and as water might get down while washing the decks, with which they were nearly flush, and as, also, they might be made the means of annoyance to those below in various ways, they were closed.

Several kinds of bellows have been adopted, from time to time, for withdrawing the air, having a hose connected with them, by which the air could be forced entirely out of the ship. In some ships, the boxes of two of the pumps have been removed, and a cylinder twenty inches in diameter and about two feet in length placed upon the top of the pump. This cylinder is fitted with proper valves and a piston, and forms an air-pump. The pumps are thus converted into air-tubes ; the piston of the air-pump is connected with the brake which works the other two pumps, and is moved with them. By this plan, the air of the well can be frequently withdrawn, without danger of its escaping into other parts of the ship.

Through the kindness of Lieutenant Charles Henry Davis, of the United States navy, to whom I am indebted for several suggestions, I was enabled to visit the United States ship of war Ohio and the frigate United

States, and also to obtain information from the department at Washington as to plans of ventilation which had been already tried, and their results. The Ohio is a ship-of-the-line, of seventy-four guns, and has the pumps fitted up in the manner just described, and also the ventilating-tubes. These last were all carefully plugged up and neatly painted ; a sufficient indication of the importance attached to them as ventilators. The United States is a frigate of forty-four guns. The following plan for the ventilation of ships was the result of observations upon these vessels. It is not put forth as a perfect system, but as one which may be adopted with a strong prospect of relieving sailors from the severer effects of a deficient supply of air.

In examining these ships with regard to ventilation, the great difficulties were in finding air-channels, and a position in which a moving power could be placed, where it would be out of the way and yet be permanent and ready for use. In constructing a vessel, there is very little doubt that channels could be obtained in the sides sufficient for a good system of ventilation, without in the least encroaching upon the available room. In those already built, there are channels which could be made valuable for the ventilation of the orlop-deck, where, I believe, it is most needed. About three feet above this deck, a space about eight inches wide is left unplanked, for the circulation of air among the timbers, and is termed the air-streak ; this opening extends fore and aft the vessel, and is covered by a plate of copper,

perforated with holes about one fourth of an inch in diameter. A similar air-streak is also left in the hold. If this last be covered with a box, through the whole or a part of its extent, it will serve as a channel, through which, by exhausting the air, a current may be produced. If a horizontal fan be placed over the pumps on the gun-deck, with its shaft resting upon a support level with, or below, the tops of the pumps, the fan itself might be made to revolve close up to the deck above, and quite out of the way. With the under side of the fan, in which should be the central opening, a trunk could be connected, which should pass down by the side of the pumps, be of any shape which is most convenient, and terminate in the top of the well. The fan might be put in motion by a rope, passing round a pulley on its upright shaft, and through a block at a proper distance. Two or more men, by pulling upon the rope, would produce a rapid rotatory motion in the fan. The communication between the box over the air-streak and the well is effected by a transverse wooden channel in the hold, secured to the under side of the deck. The foul air may be discharged by a port-hole on either side of the ship, according to the direction, and for this purpose a discharging trunk can be placed between the beams supporting the deck above, quite out of the way; the trunk may be of painted canvass or of wood.

By this arrangement it is easy to see that the orlop-deck (as in the Ohio) may be thoroughly ventilated, and through that, by means of the hatches and ladder-

ways, the decks above, if necessary. By erecting a wind-sail, air may be brought down to the orlop or any other deck, without being in the least contaminated by passing through the decks above. It will also be observed, that the pumps remain untouched, and that the communicating channels and fan are in positions where they will be as little objectionable, on account of the room they occupy, as can be expected. The thickness of the fan need not exceed one foot, and could be made even less, and its diameter could be three or four feet ; consequently it would not extend beyond the pumps, neither would it interfere with any movements about them. The space in the orlop-deck through which the pumps pass is usually surrounded by panel-work, or bulk-heads, as they are termed, within which sufficient space can be found for the air-trunks.

The preceding plan is not proposed as affording a perfect system, but as one which there is good reason to believe is practicable, and which will greatly improve the state of the air in those parts of a ship in which it is most needed. A similar plan adopted in the construction of a ship, with the formation of channels between the timbers for each deck, could be rendered still more effective.

The ventilation of *steamboats*, either upon the ocean or rivers, can be effected with very great ease, as the mechanical power for moving a fan can at any time be obtained. A separate engine is usually provided, in large boats, for driving the fan required to blow the fire under

the boilers. This engine could be made to drive a ventilating-fan also, or, possibly, if the air of the boat is not too much vitiated, the fan for the boilers can be supplied by pipes connected with the cabin and other places to be ventilated. In either case, fresh-air channels are to be placed along the sides of the cabin, at proper intervals, opening near the floor, while foul-air tubes pass along near the ceiling, fore and aft, leading the vitiated air eventually to the fan.

Those who have occasion to travel in the night-boats, when crowded, must be well aware of the state of the atmosphere in the cabins when the passengers are in their berths, and of the almost utter impossibility of obtaining, from this cause, a comfortable night's sleep; indeed, some passengers are compelled to pass the night on deck, being incapable of supporting the hot and offensive air in which they are enveloped below. A very small sum of money expended in the manner proposed would entirely relieve the passengers, and greatly increase the popularity of the boat.

CHAPTER XVI.

ANATOMICAL ROOMS.

Anatomical Rooms often disgusting from Want of a proper System of Ventilation. — Deficient Ventilation may be the remote Cause of the fatal Results of Wounds received in Dissecting. — Parent-Duchâtelet's Anatomical Table. — Closet for Maceration. — Description of ventilating Arrangements for an Anatomical Room.

ANATOMICAL rooms, as usually constructed, are frequently disgusting, from the odor of animal putrefaction, which cannot always be prevented. Several physicians, some of them eminent, have endeavoured to prove that the emanations from dead bodies are in no wise injurious to the health of those exposed to them.* However this may be, there is no proof that they are peculiarly healthy, and abundant evidence that they are exceedingly disagreeable, especially to young students in anatomy. Under a proper system of ventilation, all odor in the rooms may be removed.†

---

* It is well known that students receiving wounds while pursuing anatomical examinations, especially in recent subjects, sometimes become very ill, and not unfrequently die. We are by no means sure that a portion of the poisonous matter is not absorbed by the lungs; we know, indeed, that there are some poisonous gases which are exceedingly active when entering the lungs; we know, too, that one of these gases, sulphuretted hydrogen, is given off during decomposition.

† The means usually employed to disinfect anatomical rooms is

To effect the complete removal of odor, we must not only place the subject itself under the influence of a current of air, but also those portions which have been examined, unless they are immediately removed, and likewise the vessels in which parts are undergoing maceration, for the study of the bones and their ligamentous connections.

The anatomical table of Parent-Duchâtelet prevents the escape of odor from the subject completely. This table may be constructed of wood, or, what would be better, both for cleanliness and permanency, of cast iron ; it is hollow, and covered by a coarse wire netting or lattice-work. Communicating with the interior of the table is an air-trunk, which passes beneath the floor, and terminates in a chimney. Into this chimney the smoke passes from the boiler, which is indispensable in every anatomical room, and from the stove or other heating apparatus. It may be observed, that an open fireplace would be inadmissible in the apartment. The heat which is thrown into the chimney from these sources is intended as a moving power to the ventilating current.

When a fire is lighted in the stove, or under the boiler, a current is generated in the chimney, to supply which air enters from the apartment, passes down by the subject, through the hollow tube and the air-channel beneath the floor. Consequently no disagreeable odor can

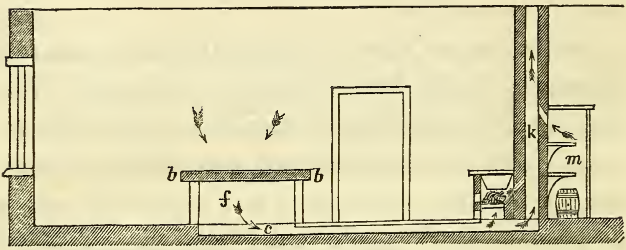
---

chloride of lime, a substance between the unpleasant odor of which and that of decomposing animal matter it is difficult to choose.

escape into the anatomical room, whatever be the condition of the part under examination.

Fig. 60 is a longitudinal section of the anatomical room, in which *b b* is the table, *f*, the hollow space in the pedestal, communicating with the air-channel, *c*.

Fig. 60.



From the air-channel the larger portion of the air passes immmediately to the chimney, *k*, a small part only supplying the fire of the boiler, the flue of which communicates with the same chimney.

The net-work cover may be made of large tinned iron wire, secured to a frame, with the meshes sufficiently large to allow the hand to be introduced to remove a knife or other article which may fall through. Beneath this cover, which should be movable, is placed a metal trough, represented by *c*, in figs. 61 and 62,—longitudinal and transverse sections of the table. This trough is lower at one end than the other, that all liquids may flow towards the tube *h*, and through that into the pail *i*, beneath. Near the top of the trough is a row of holes by which the air entering through the net-work passes from the interior of the trough into the hollow support, *f*, of the

table, and thence into the canal, *g*, beneath the floor. Beneath the trough is placed a sufficient number of blocks, *d d d d*, to give it a firm support. All parts of the table

Fig. 61.

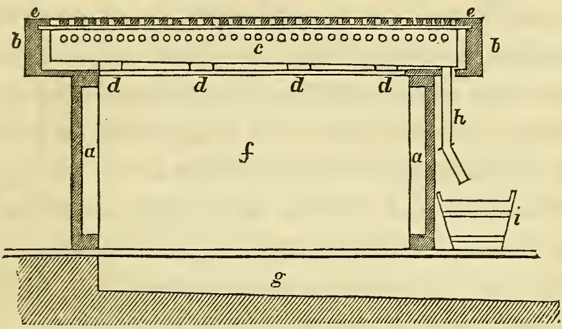
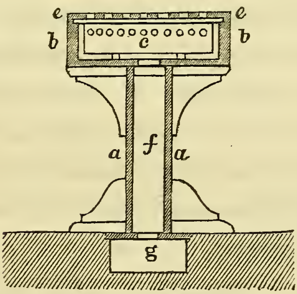


Fig 62.



and its connections should be made air-tight, and the tube through which the liquids escape should be closed by a proper stopper. Those parts which are not under immediate examination may be covered by a large cloth, that the draught may be increased to the desired amount in the remaining portions. The table, or the air-channel connected with it, should be fitted with a valve, by

which a current from an unoccupied table may be diminished or completely cut off.

The ventilation should be kept up night and day, which can readily be done by the use of anthracite coal, burning slowly and in considerable quantity. During the night, the subject might be placed under the influence of air colder than that of the anatomical room, by covering the whole table with a large cloth, and allowing the external air to enter through a tube passing under the floor, and rising at one or both ends of the table, beneath the cloth ; with such an arrangement, none of the air of the room would come in contact with the subject. It would be possible, by similar means, at all times, to place those parts not under actual examination in a current of external air, by which decomposition would be much longer delayed than when exposed to air of the usual temperature of anatomical rooms. It would be well to have a grate within or at one side of the chimney, communicating immediately with it, expressly for ventilation, and which could be used without warming the apartment.

The process of maceration is that during which the most offensive emanations are given off, and the vessels in which it is conducted should be exposed to a good current. The arrangement for effecting this is represented in fig. 60. A closet, *m*, is built against the side of the room next the chimney, and communicating with it by an opening near the top. The front of this closet may be fitted with doors, leaving a narrow opening at

the bottom for the admission of air, or may be closed by a curtain running upon a wire at the top, and leaving, like the doors, a space at the bottom.

Within the closet are several shelves ; beneath the lower range the macerating vessels may be placed, concealed by a door, if desired. Upon the shelves ligamentous preparations and examinations can be made, and subjects deposited.

In arranging the windows of rooms especially for investigations in pathological anatomy, it is well to have the principal light from the top ; in addition to this, it is desirable to have one window opposite the end of the table, that light may fall horizontally into the cranium, and deep into the thorax, the body being reversed by raising and reversing the movable frame of net-work upon which it is placed.

CHAPTER XVII.

CHIMNEY-TOPS, TURN-CAPS, AND VENTILATORS.

Action of Turn-caps not well understood. — Wind blowing horizontally over a Chimney-top, however strong, does not diminish discharge of Smoke. — Contraction of Chimney-top in most Cases sufficient to prevent Smoking. — Action of a Current of Air when moving in the Direction of the Smoke. — Saint-Martin's Chimney-top. — Tredgold's. — Various Forms of Tops. — Comparative Value of Turn-caps. — In a strong Wind any Cowl effectual which protects the Flue from the direct Influence of the Wind. — In a light Wind Cowls often injurious to the Draught of a Chimney.

The object of turn-caps upon chimney-tops is to protect them from the influence of currents of wind, which may descend upon the flue and prevent the escape of smoke, or force it into the apartment. They are also used to increase, in some instances, the velocity of the smoke in the chimney. There are few objects on which so much time has been spent and misspent, and for which so many patents have been taken out for the same form and for different forms, as for turn-caps. Their great variety, and the constant changes in their arrangement, are proofs that more is expected of them than they accomplish, and that the principles upon which they act are not well understood.

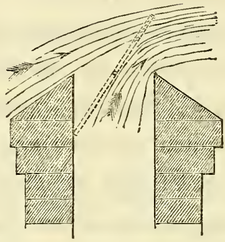
When a chimney stands alone, and is not over-topped by other objects, its draught will depend upon its height

and temperature, and be but slightly influenced by the wind. It might at first seem that the wind blowing horizontally across the top of a chimney would prevent the escape of smoke ; but it is not so ; the velocity of the escaping gases compensates for the diminished section, as is easily shown, both by experiment and reasoning. In every other direction, the wind may or may not have an influence upon the draught, according to its velocity, and according as its direction coincides with or opposes that of the draught.

In most cases it is found sufficient to diminish the chimney-top, as has already been mentioned in a former chapter, by which sufficient velocity is produced in the ascending current to overcome any slight unfavorable circumstances in the direction of the wind. When the ascending current is feeble, this may not be sufficient ; it may even be a disadvantage, for every contraction is attended with a loss in the total discharge. In such cases, it would obviously assist the escape of the smoke, if we could give the wind the same direction as the smoke. This is frequently accomplished, to a certain degree, by means of a conical chimney-top, as is seen in the following figure (fig. 63). Air moving as indicated by the arrows, and striking the inclined surface, is deflected and assumes the direction of the surface against which it impinges ; this it does in all cases, whatever be the form or direction of the surface. In this case the wind takes an upward direction, approaching more or less that of the smoke, and increases its velocity.

The velocity is increased in two ways. First, according to the general principle by which the motion of

Fig. 63.

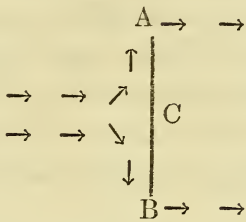


a fluid is communicated to the lateral parts which are at rest. We have already* given an example of this action; the fall of water in a flue, drawing along with it sufficient air to produce a draught for the fire under an engine-boiler. The same communication of motion occurs in ordinary chimneys, through the influence of air upon air, but to a less extent; wind passing rapidly in a direction approaching that of the smoke, as in fig. 63, draws along the smoke, and increases the draught. Of the cause of this lateral communication of motion no satisfactory explanation has as yet been offered. Secondly, when a current of air impinges upon a surface (A B, fig. 64) perpendicular to its direction, it flows out towards the borders of the surface, and, after reaching its borders, tends to pursue its original direction, under the influence of the general current; as that direction is also nearly perpendicular to the surface A B, there will be a point, C, behind the surface, into which air can find its way only by change of direction of the general current, which does not immediately take

* See ante, p. 101.

place, and from which air is drawn under the influence of the principle just stated. A direct consequence of

Fig. 64.



the action of these two principles must be a diminished atmospheric pressure at the point C; and a tube placed with its mouth at this point, and the other extremity reaching beyond the borders of the surface A B, will have a current established through it.* Now the direction of the current, fig. 63, is upward after striking the inclined coving, and the mouth of the chimney is in the point of diminished atmospheric pressure; consequently the velocity of the warm air in the chimney will be accelerated.

It is clear from the preceding explanation, that any increase of velocity in the smoke will depend upon the velocity of the impinging current, and will be null in a calm. From experiments made upon the conical chimney-top by its inventor, Delyle Saint-Martin, a lieutenant in the French navy, it appears, that, when the

* The most familiar illustration of this effect of a current is had in that of water flowing by the square pier of a bridge; the surface of the water is always more or less depressed behind the pier.

impinging current had a velocity of fifteen feet per second, that of the ascending current was five feet per second, or about one third.* Perhaps there is no other form of chimney-top which affords so many advantages; it draws out the ascending smoke, and increases the draught; it contracts the chimney, and gives the smoke greater velocity at the moment of escape, and at the same time opposes the entrance of the wind into the chimney-flue.

A great variety of chimney-tops have been in use, generally arranged with reference to the particular wind to which the chimney is exposed.

The most common is the T, with the cross-piece cylindrical, as in fig. 65, or enlarging at the extremities. To this is sometimes added the end-pieces, as in fig. 66, or portions of cylinders at right angles, and opening above and below, as in fig. 67. As a still

Fig. 65.

Fig. 66.

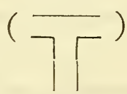


Fig. 67.

further security, end-pieces are sometimes applied to each of the four openings.

Fig. 68 represents a form of top which, for the

* Journal de Physique, 1788, Tom. II., p. 161. The chimney-top of Saint-Martin was composed of two hollow truncated cones, of the same dimensions, one above the other, with the flue terminating in the lower cone. The lower borders of the upper cone descended a little below the top of the lower.

most part, places the draught beyond the influence of winds, whatever may be their direction. The side-piece A B is cylindrical, open at the top and bottom, and much larger than the flue over which it is placed. Above the cylinder is placed a plate, or a portion of a sphere, with the convex surface upwards. Instead of a cylinder, the piece A B is sometimes made conical, with the base downward, or with both ends contracted, by which it is made to assume a spherical shape, with portions removed from the upper and under surfaces. This form is very common on board United States vessels for the protection of the galley-funnels.

Fig. 68.

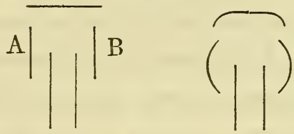
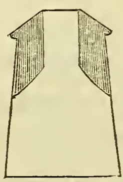


Fig. 69 represents that recommended by Tredgold.

Fig. 69.

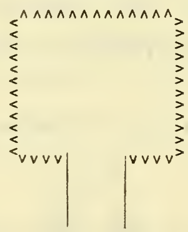


It is similar to the one first described; it has, however, an additional advantage, that of giving the proper contraction to large flues. The cap is made of copper or plate-iron well painted, that it may slide into the

chimney-pot or the top of the chimney. In the figure, the contracting-cap is inserted in the chimney-pot. The external aperture is made of the proper dimensions, and the space between it and the pot is filled by a sloping conical surface, for the reasons above mentioned. The dimensions of the opening are preserved the same for a certain distance down the flue, after which the cap gradually assumes the size of the flue. The curve here indicated is found to be advantageous in preventing eddies, and directing the smoke towards the outlet.

A top has been contrived, which is said to be more satisfactory in its action than any other. It is made in the form of a large cylinder, closed at the top, and communicating below with the smoke-pipe, as in fig. 70.

Fig. 70.



This cylinder, which is made of copper or sheet iron, is pierced from within outward with a great number of square holes, the pieces of the metal which are forced outward forming small truncated pyramids projecting externally, like those formed upon the bodies of the tin lanterns formerly in common use. Experiments have been tried with this top by placing it upon a stove-pipe in which a smoke was made, and exposing the top

to a blast from a centrifugal fan, but without in any degree preventing the free escape of the smoke. The only inconvenience to which it seems liable is the accumulation of soot in the openings, by which it may be gradually obstructed. It has been recommended for those chimneys which rise but little above the roofs of houses, and which are subject to downward draughts from all quarters.

The advantage derived from giving the escaping smoke and the wind the same direction has led to placing upon the chimney a movable cap, or turn-cap, by which the opening should always be turned from the wind ; the wind is then not only prevented from entering the flue, but, in accordance with the principles already explained, increases the draught to some extent when its velocity is greater than that of the smoke.

The simplest form of turn-cap is a short cylinder, somewhat larger than the flue upon which it is placed, and around which it turns upon an axis fixed in the centre of the flue. It is closed at the top, and has about one third of its surface removed, for the escape of the smoke ; upon the top is placed a vane, by which its direction with reference to the wind is maintained. Where a portion of the surface is removed in this way, it is found necessary to place pieces of metal on the sides of the opening, or a single piece in the middle of the opening, against which the wind may act and aid in turning it.

Instead of removing a portion of the cylinder, the cap

is made as in fig. 71, D, and is surmounted by the vane, as in the other form. To this is frequently added a tube of less diameter than the cowl, passing from its back, where it is tunnel-shaped, into its interior, until it passes the opening of the upright flue ; as shown in the section I, fig. 71. This last form is found to be more efficacious, inasmuch as it affords more surface for the impinging current to act upon and draw up the air ascending the smoke-flue ; its tunnel shape may also increase the velocity of the wind passing through it. It is called the blow-pipe cowl.*

Experiments were made in 1842 by Mr. T. Ewbank, to determine the comparative value of several forms of chimney-caps and ventilators. The cap was placed upon a glass tube of an inch and a quarter bore and twenty-eight inches long ; its lower extremity descended into a vessel of water, and its upper extremity, bearing the model of the particular cap to be tried, was placed in a blast of air from a pipe three inches in diameter. The blast was derived from the blowing apparatus of an iron foundry, and was kept as equal as possible. The results were as follows.

1. The glass tube was placed perpendicularly with its open end in the centre of the blast, the axis of the

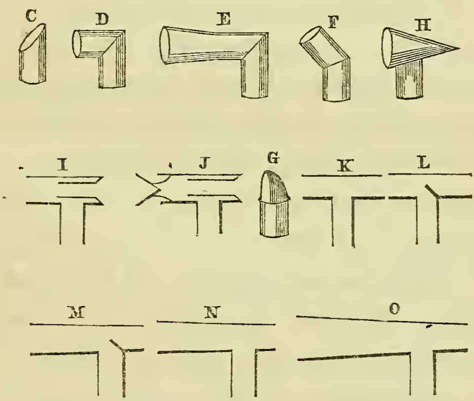
---

* This form of cowl has been several times reinvented, and is said to have been not long since patented in the United States. It was introduced into the British navy more than twenty years ago, by Captain Warren, who had seen it on board a French frigate. See Mechanics' Magazine, Vol. II., p. 338, where it is figured and described.

tube and that of the blast being at right angles to each other. No change in the level of the water within the tube was perceived.

2. The tube C was placed upon the glass tube, the open portion being turned from the blast. The water rose in the glass tube from $1\frac{3}{4}$ to $2\frac{1}{2}$ inches. With the open portion at right angles to blast, no movement of the water.

Fig. 71.



3. D, when placed with the horizontal branch in the direction of the current, raised the water from $1\frac{1}{2}$ to $2\frac{1}{4}$ inches; horizontal branch making an angle of 45° with current; water $3\frac{1}{4}$ inches; when making angle of 90°, water $2\frac{1}{2}$ inches.

E produced no greater effect than D.

F, it was supposed, would have been more effectual, but it was not tried.

4. G is a hood, the back of which forms an angle

of 30° with the side of the pipe on which it is placed; its position was with the opening turned from the blast. Water raised from 3½ to 4½ inches. Turning the opening into any other position diminished the effect.

5. H gave 2½ to 3½ inches of water; when in the direction of the current, at right angles to it, it gave 4½ inches. Various models were tried, but in all it proved inferior to G.

6. I is the blow-pipe cowl; outer case, 4⅞ inches long and 1½ inches bore; inner tube ¾ of an inch bore; conical portion to catch the wind, 2½ inches long. Water raised 4½ inches when axis of cap in same direction as axis of blast; at 45°, 3½ inches; at 90°, ½ inch.

7. J, same cap with a cone on its open end to prevent currents of wind from entering it. Water raised 2¼ inches in direction of current; at 45°, 1¼; at 90°, level.

8. K, having the perpendicular and horizontal tubes of the same diameter; the latter, 2½ inches long, in the direction of the axis, gave no elevation, occasionally a depression; at 45°, 4 inches; at 90°, 2 inches.

L, the same as K, but with a projecting piece so as partly to cover the perpendicular tube, gave 4½ inches.

M has its horizontal portion 6 inches long and conical, with the larger diameter 2 inches. It gave 8½ inches.

N, same as M, with the projecting piece removed. Water rose from 13 to 15 inches.

A short conical tube, whose mouth flared out to two inches, was inserted in the smaller end of N. Water, 18 inches. A longer tube, whose mouth reached to the orifice of the blast tube, caused the water to rise out of the glass tube, which was 28 inches in length. The surfaces of contact in the two currents, the impinging and ascending, in this case are large, since the first passes through as well as over the cap, and its direction is outward as it leaves its mouth ; it is this combination, probably, which gives it its efficiency.

9. O, like N, but having the horizontal branch $1\frac{1}{2}$ inches bore, gave from 16 to 18 inches. On adding the short diverging mouth-piece in the same manner as to N, the water rose from 22 to 24 inches.

From these experiments, it is inferred that the last is the best form of turn-cap. It is suggested, that a conical tube might be placed in the smaller end, projecting but very little beyond it, a little farther at the under side than the upper, the more readily to catch the descending currents, but not so much as to prevent the wind from sweeping close around the exterior of the horizontal branch.*

It is, however, very difficult to judge of the efficiency of turncaps from experiments like those just detailed. The force of the blast was greater than that of the winds to which the caps will usually be exposed ; and if the blast was that generally employed in iron foundries, it must have been greater than that of violent

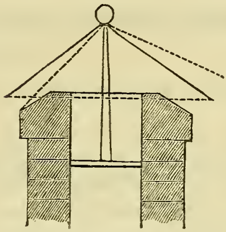
* Journal of the Franklin Institute, 1842, 3d series, Vol. IV., p. 104.

hurricanes. It is very questionable, notwithstanding the great apparent difference in the experiments between these different forms, whether they have any very decided advantage, practically, over the simple cowl with its back to the wind ; indeed, we see that the cap G, which is a simple hood, is better than the conical cap H, or Espy's ventilator, as it is usually termed. It would be a great assistance, in determining the comparative value of the caps, to know the relative velocity of the impinging and ascending currents.

In a strong wind, any cap will be effectual which prevents the wind from beating directly down upon the chimney ; this may be done by any of the forms in fig. 71. In a light, unsteady wind, the time when the cap is most needed, it is subject to a disadvantage which it is difficult to obviate. The friction is always considerable, and, under the circumstances just mentioned, the opening of the cowl will often be directed towards the wind ; in this position, the wind will have but little influence upon the vane, and the smoke, if the draught is feeble, will be driven into the apartment. The steadiness of the cowl may be increased by making the vane double, the two sides forming an angle of ten or fifteen degrees (<). The single vane in common use, receiving no pressure from the wind when in its direction, has the same tendency to flap as a loosened sail. The friction may be diminished by nicer workmanship, and the noise lessened by allowing the cowl to run in leather collars ; but the objection we have alluded to will only be diminished, not removed.

Fig. 72 is a section of a cowl which is not liable to this objection. It is a cone balanced upon a point in

Fig. 72.



such a manner that it may be tilted in any direction. The wind blowing upon it depresses the side upon which it strikes, and at the same time elevates the opposite side ; the wind sweeping over it exerts some influence upon the ascending current. During a calm, it hangs with its base horizontal, and offers no impediment to the escape of the air around the whole circumference. We have used the fixed cone in some cases with great advantage, especially when fitted up with the deflecting board (see page 253).

A simple plate is sometimes used, moving on an axis fixed across the flue, as indicated by the dotted lines in fig. 63. It is obvious that it will, under the influence of the wind, assume a direction which will prevent its entering the chimney. It will act in two directions only.

Since turn-caps are liable to several objections, we should, wherever it is possible, — and the circumstances must be rare in which it is not, — construct a fixed chimney-top, to remove the flue from the influence of the wind and improve its draught.

CHAPTER XVIII.

DRAINAGE.

Sewerage, its Influence on the Health and Mortality of a District. — Forms of Sewers. — Curved Sewers most advantageous. — Systematic Drainage. — Importance of Plans and Levels of Cities with Reference to Drainage. — Amount of Fall in Sewers. — Materials for Sewers. — Angle of Junction of Sewers. — Of Cleansing. — Flushing. — Water-closets and Privies. — Supply of Water for Water-closets. — Of preventing offensive Odor from Privies. — McLean Asylum, Drainage of.

The removal of impurities by properly constructed sewers is intimately connected with ventilation, since it can hardly be expected that the essential requisite of ventilation, *pure* air, can be obtained, when the ground is covered by putrefying matter, or soaked with refuse water. Under some circumstances, it may be even better to submit to the consequences of a stagnant atmosphere, than introduce air which is already impure from these causes.

The influence of deficient sewerage on the amount of sickness and the mortality in a district has been long known to physicians, and has been more recently confirmed by careful statistical investigations. In some towns, the mortality has diminished more than twenty per cent. after the introduction of proper sewers and drains. The amount of sickness prevented by the same

means is not to be ascertained so accurately ; but an approximation may be made, if we consider that the results of some medical institutions give about twenty-eight cases of sickness, of nearly three weeks' duration each, for every death.

The form of sewers has great influence upon their effective action. When the bottom is flat, especially if the water is shallow and the flow slow, a large amount of deposit is left. The water flows sometimes in a channel, leaving a deposit on each side, and sometimes upon one side, leaving a deposit on the other. If, however, the stream, instead of being thus scattered and diminished in force, be kept in a mass, preserving as great a depth as possible, these evils will be avoided. This object is attained by giving the bottom of the sewers an arched or semicircular form. The amount of deposite is said to have been diminished one half by substituting the arched for the flat bottom.

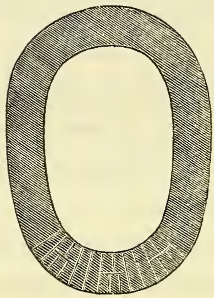
Another advantage of the curved sewers is the increased strength ; and for this reason the sides also should be curved. Sewers with flat sides, in clayey ground, are not unfrequently forced in by the pressure of the surrounding earth. To these may be added a third recommendation, a diminished expense of construction for the same capacity and strength.

Improvements have been lately introduced into the drainage of cities, by which it has been conducted upon a system. Plans and levels are made of the whole district to be drained. The common sewers are laid

with reference to the amount of water they are to carry, and its velocity. The builder may also, by these plans, ascertain the level at which the bottom of his cellar or his house-drain must be placed, that all refuse water may be conducted into the common sewer.

The following figure (fig. 73) represents the form

Fig. 73.



adopted in the new sewers of London. Its transverse section is egg-shaped, with the smaller end down, the vertical diameter being at least double the horizontal diameter. The bricks forming the bottom are made with radiated sides. Many of these sewers are constructed and found to answer well with a fall of but two inches in 100 feet; and in one instance, where a small stream was conducted through the sewer, the fall was at the slight rate of 1.63 inch — less than $1\frac{3}{4}$ inch — in 100 feet; and yet, slight as it is, it is kept perfectly clean.

The drains of houses are smaller, and, from various causes, more liable to obstruction; they are therefore differently constructed. Figures 74 and 75 represent

in section two of their forms which are well adapted to cleanse themselves; the inclined bottom, approaching the form of that just described. The first is laid with

Fig. 74.

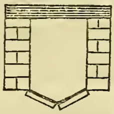
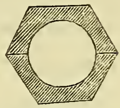


Fig. 75.



bricks, and covered by flat stones. The second is composed principally of clay, burnt, and forming a kind of tile. The drain is made in two portions, each of which is usually from 18 to 24 inches in length, and placed one upon the other, as represented in the figure. The flat sides are preferred to the circular, inasmuch as they afford a firmer bed for the under portion, and a broader bearing surface at the line of junction. Both of these forms afford means of raising the covering of the sewer for the removal of obstructions, without destroying the structure.

All right angles and sudden curves in sewers should be avoided; eddies are occasioned and deposits of sediment formed, which would otherwise pass off; the flow of water through such sewers is also diminished by the resistance offered by their sides. It has been ascertained by Mr. John Roe, an engineer who has charge of two divisions of the London sewers, that the time occupied in the passage of an equal quantity of water along similar lengths of sewer with equal falls was, —

Along a straight line . . .	90 seconds.	
With a true curve	100	"
With a turn at right angles . .	140	" *

In some of the best sewers, no curve is allowed of less radius than 20 feet, and the fall is increased at the curvature to compensate for any loss in velocity it might otherwise sustain. When sewers join, they should not meet at right angles; the side sewer should fall into the main by a curve tangent to the direction of the main, by which means eddies are avoided. The resistance due to a junction at right angles, to a junction with a curve of five feet radius, and to a junction with a curve of twenty feet radius, with a velocity of $4\frac{1}{2}$ feet per second, has been calculated to be as follows: —

For a curved junction of 20 feet radius, resistance,		100
For a curved junction of 5 feet radius,	"	146
For a junction at right angles,	"	316

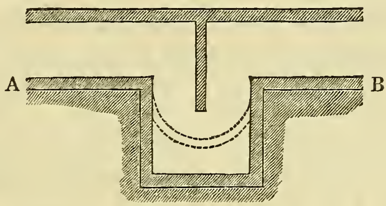
The latter increasing the resistance more than 200 per cent.

It is important that all sewers and house-drains should be so constructed that air shall not escape from them into the streets and houses. This escape

* Report from the Poor-law Commissioners on the Sanitary Condition of the Laboring Population of Great Britain, July, 1842, p. 376. It is quite remarkable, that, according to the experiments of M. Venturi, the expenditures from a straight tube, a curved tube in a quadrantal arc, and an elbowed tube having the angle 90° (each being placed horizontally), *cæt. par.*, are nearly as 70, 50, and 45 (precisely the proportions given above). See Nicholson's Journal of Philosophy, 4to, (which contains Venturi's entire work,) Vol. II., p. 487.

frequently occurs when the outlets of the drains are exposed to the influence of a strong wind, or they open into the docks, when the tide rises into them and drives the air before it. The contrivance by which this is prevented is the stench-trap, represented in section (fig. 76). It is usually made square, as represented in

Fig. 76.



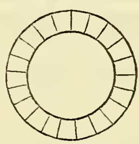
the figure ; the bottom of the well descending sufficiently below the bottom of the drain to allow space for the water to flow freely under the perpendicular division, which descends about four inches beneath its surface. When the water fills the trap to a level with the bottom, A B, of the drain, no air can pass from one side of the division to the other. An improvement on this form is to make the bottom and sides of the well curved instead of flat, as indicated by the dotted curved line ; the sediment is then more freely removed by the flow of water ; practically, traps thus constructed are very much less liable to become clogged. The odor of drains perceived in unoccupied houses is often owing to the evaporation of water from the stench-trap, which allows the air to pass through it.

Several modes have been devised for cleansing sew-

ers. In many cities, the sewers are large enough to allow workmen to enter them, and remove the obstructions by means of buckets or barrows. This is probably, in large cities, the most common mode. There are, however, objections to it, and lately the system of *flushing* has been introduced. It consists in fixing gates in the sewers, by which, when desired, the ordinary flow of water may be made to accumulate ; the gates are then opened, and the force of the water is sufficient to sweep off the deposit. The stench-traps are frequently made square, as represented in fig. 76, and deep, for the purpose of collecting all the sediment, and from which it is removed through openings communicating with the street above. It is obvious that a free supply of water will in all cases render the sewerage more simple and efficient.

In Boston, since 1827, the common sewers have been made round, and about twenty inches in diameter (fig. 77).

Fig. 77.



They are built of hard burnt bricks, set edgewise, the lower portion being laid in cement, and the upper in mortar. The fall is seldom less than eight inches in one hundred feet, an inclination which is easily obtained in this city, situated, for the most part, upon ground many feet above tide-water. All sewers empty into the

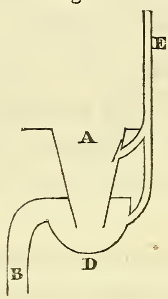
docks about two feet above the bottom, from which impurities are swept away by the tide-water. Sesspools are constructed at intervals of about two hundred feet, both for the formation of stench-traps and for cleansing the sewers. These are about two feet long, by twenty inches wide, and descend two feet below the bottom of the sewer. In all cases, a well about two feet square is made to them from the street above ; they are cleansed twice during the year, — once in the spring, and again in the autumn. The barrel drain has never, as yet, been stopped by sediment, although the flat-bottom drain in the immediate vicinity has been repeatedly completely obstructed.

The air of houses in cities is often rendered unpleasant by the emanations from privies. A part of these emanations must exist, where privies are not frequently cleansed, and where they are under the same roof with the house, or very near to it. Another source is the percolation of the fluids of the vault through its walls, sometimes into the rooms of adjoining houses. The foundations of houses become saturated with the foul water, and the atmosphere so tainted that it is said meat cannot be kept a single night without becoming injured.

The best mode of obviating these evils is the abolishing of vaults and privies, and the substitution of water-closets. Of these there are several in use ; that most frequently met with is the "pan-closet." This is efficient, but requires that a handle should be raised, that

the water may flow and wash the soil-pan ; the handle might, however, be connected with the door in such a manner that the shutting of it should give the requisite movement to the handle. A simple kind of closet has been recently invented, and is in common use abroad ; it is represented in fig. 78. A is the soil-pan ; B, the soil-

Fig. 78.



pipe ; D, the stench-trap, or D, as it is usually called, which is filled with water to the bottom of A ; E, the pipe supplying water, one branch going to the pan, and another larger branch to the D, by which it is thoroughly washed, and its contents forced into the soil-pipe. A third form consists of a pan, connected, by a pipe four or five inches in diameter, with a drain, through which all the water from a pump-shoe passes ; the pan is occasionally washed by pouring water into it. There are objections to this plan : first, it is much less effectual in preventing disagreeable odors than either of the others, even if the drain is well trapped ; secondly, unless the quantity of water passing through the house-drain is sufficient, it will become obstructed ; thirdly, the sess-

pools of the common sewers, into which the house-drains empty, require to be frequently cleansed. This is because the water passing through the drain is not sufficient, as in the other two forms, to keep the solid matters in a state of suspension. But where the quantity of water passing through the common sewers is large, and the fall considerable, this plan has been found to answer tolerably well.

It may be objected, that the expense and care required to keep closets in order will prevent their introduction to any considerable extent. But it is very questionable whether, in most cases, the first cost of the privy and vault is not greater than that even of the pan-closet, the most expensive of the three kinds just described; if to this we add the expense of cleaning and the injury often done to the buildings by the night-men, it will be much more than a set-off to the necessary repairs of the closet. If the second form of closet were adopted, which can be furnished at about half the price of the first, it will be found decidedly the cheapest, in every respect.

In winter, in cold climates, there is some danger that the water in the pipes may be frozen; but this can always be obviated by placing the water-closet in such a position that the soil-pipe may pass down near the kitchen chimney, the waste heat from which would be quite sufficient, not only to prevent the water in the pipes from being frozen, but that in the cistern also.

With regard to a supply of water, no difficulty can

arise, except in places which have no public provision ; in such situations a forcing-pump and small cistern will, at little expense and trouble, provide all that can be required. In most cases, the cistern alone will be needed, since it can be filled by the rain-water collected from the roof.

Several methods have been tried for separating the liquid from the solid portion of the collections in vaults. If this separation could be readily accomplished, and the liquid allowed to flow off into the common sewer, no inconvenience would result as far as the sewer is concerned, and as the liquid is six times the bulk of the solid matter, the vaults would require cleansing less frequently, in the same proportion.

One plan for effecting this purpose consists in placing a leaden pipe, two inches in diameter, pierced with holes about half an inch in diameter, in the vault, reaching from the top to the bottom. The lower end of the pipe is connected with a drain or sesspool, into which the liquids pass, leaving the remaining portions comparatively solid.

Instead of vaults, casks are sometimes used, into which all refuse matter falls through a tube five or six inches in diameter, and from which the liquid is allowed to flow into other casks, or into drains, by means of the pipe just described. The casks, when filled, are removed, and the openings properly secured, after which they can be transported without inconvenience to any distance.

When a vault cannot be avoided, the adoption of the first of these plans will materially diminish the inconvenience ; still the house with which it is connected will be liable to receive the emanations from it. The following arrangement has been found to prevent, under ordinary circumstances, the escape of gases from the vault itself ; but it does not prevent the saturation of the foundations and earth in its neighbourhood, and the consequent contamination from these causes. The vault is made as tight as possible, by means of cement, and no air is allowed to enter it, except through the seat. A trunk, either of wood or metal, six or eight inches square, its dimensions depending upon the size of the vault and the draught which can be established in the trunk, is placed beneath the seat, and connected with a flue in contact with the kitchen chimney, or some other chimney in which there is a constant fire. If such a flue cannot be obtained, a pipe of sheet iron, or, what is better, cast iron, may be placed in the chimney, reaching five or six feet above the fire, that it may not interfere with the draught. By this means, we shall be able to produce a downward draught into the vault, while the heat to which the gases are exposed in the chimney raises them to a height from which they will be rapidly dispersed without annoyance. This arrangement has been found so successful, that, in all cases where the privy is to be placed near the house, it will be well to construct a flue for this purpose ; even in water-closets it would not be amiss to take the same precaution.

It is now well ascertained that all the accumulations of which we have spoken may be rendered nearly inodorous by mixing them with a sufficient quantity of water, and that in this state they may be thrown upon grass land, or allowed to flow over it, with the greatest advantage.* At the McLean Asylum, at Somerville, this principle has been practised upon for the last twenty years. All the refuse matter from the water-closets and sinks, and the water from the baths and pump-shoes, is emptied into sewers which conduct them with a rapid fall to the garden, about six hundred feet distant. In the garden, they are allowed to flow over the grass, which is always very remarkable for its luxuriance, and occasionally to a quantity of earth and sods, which, after becoming sufficiently enriched, is removed for agricultural purposes. I am not aware that any inconvenience has ever been experienced from this practice ; in summer the liquid parts are quickly evaporated or taken up by the rank vegetation, and in winter they are frozen or absorbed by the earth.

---

* Parent-Duchâtelet has found by experiment, that, when one hundred parts of water are mixed with one of the liquid matter from privies, the mixture evolves no smell, and that with fifty parts of water it is tasteless. "Car," says he, "malgrè le dégoût inséparable de pareilles vérifications, *nous n'avons pas crainte de la goûter.*" — Hygiène Publique, Tom. II., p. 386.

APPENDIX.

APPENDIX.

No. I. — p. 5.

The Production of Wax and Fat.

The statement in the text, that animals produce no organized substances, must be admitted generally; but some rare exceptions may exist. Liebig, in his treatise on Animal Chemistry, assumes that animals have the power of transforming certain vegetable substances into others possessing entirely different properties. He believes, for instance, that sugar may be converted into fat, or wax, and appeals to Huber's experiment showing the production of wax by bees fed on sugar, for support. Dumas, on the other hand, teaches that animals produce neither wax nor any other substance.

In 1843, M. Milne Edwards made some experiments on the development of wax in bees, the results of which were communicated to the French Academy, and published in the *Comptes Rendus de Séance, du Septembre* 18, 1843. In this experiment, M. Edwards analyzed a number of the bees from a swarm on which the experiment was to be made, as well as the honey upon which they were to be fed; after a time, the cells they had constructed were weighed, and a number of the bees analyzed. The results were as follows: —

	Gramme.
The fatty matter already existing in the body of each bee was estimated at	0.0018
That furnished each worker during the experiment did not exceed	0.00038
Consequently the total quantity of fatty matters furnished in the food did not exceed for each bee .	0.0022
But during the experiment each worker had produced a quantity of wax equal to	0.0064
And after having furnished this secretion, each bee contained in his body, either as wax or fat, . .	0.0042
Total, ...	0.0106

From which we should conclude that bees possess the power of producing wax or fat.

M. Edwards, although he is convinced that bees have this power, is unwilling to admit that all animals possess it. The secretion of wax is peculiar to a small number of insects, for which they are provided with a peculiar glandular apparatus, very different from the adipose tissue of other animals. If animals can transform sugar into fat, we have but to feed them upon it to fatten them ; but experience has shown that they grow lean upon such food. Hogs will not fatten well upon potatoes ; but add skim-milk, and they will. Potatoes contain but a small quantity of fat, while skim-milk contains about five per cent. Cows give the richest milk when fed upon hay containing the greatest amount of oily matter. Generally, those animals only become fat who consume fat. M. Edwards thinks that the materials constituting animal bodies should be considered as forming a certain number of distinct natural families, the different species of which may have a common origin, but are not derived from the stock or products of another group. Thus, in his opinion, nothing in science authorizes him to believe, with Liebig, that fat is derived from fibrine ; but he would readily admit that albumen may be derived from fibrine or gelatine, and that oil of almonds may become animal fat. He supposes that animals have the power of modifying alimentary substances to a certain degree, but that they produce no compounds which are not closely analogous to those from which they are derived. This seems to be the theory generally received by organic chemists and physiologists.

No. II. — p. 17.

Weight of Expired Gases.

800 cubic inches of air at 60°, and a dew-point at 40°, will weigh 263.395 grs. 800 cubic inches of air at 95°, containing 8½ per cent. of carbonic acid and 5.6 grs. of vapor, dew-point 85°, will weigh only 232.450 grs.; nearly 5 per cent. less. Hence, air, when expired, rises to the ceiling.

No. III. — p. 19.

Formulæ for the Dilatation of Gases.

The experiments mentioned at page 19 give the dilatation for 1° Cent. 0.00364, and for 1° Fah. 0.00203.

Let V represent the volume of a gas at the freezing point. V′ the volume at $t°$ under the same pressure.

Let a represent the coefficient of dilatation, 0.00364 for the Centigrade, and 0.00203 for the Fahrenheit scale; we have

$$V' = V\,(1 + a \cdot t).$$

If V were the volume of gas at $t°$, V′ the volume of the same gas at $t'°$ under the same pressure, we shall have

$$V' = V\,\frac{1 + a \cdot t'}{1 + a \cdot t}\,;\ \text{or}\ V' = V\big(1 + a\,(t' - t)\big).$$

This last formula being obtained by neglecting the terms which contain the square of a; it is much more simple, and sufficiently exact.

If the volume V were under the pressure p, and the volume V′ under the pressure p', we shall have

$$V' = \frac{V p}{p'}\left(\frac{1 + a \cdot t}{1 + a \cdot t'}\right);$$

neglecting the square of a, we have

$$V' = \frac{V p}{p'}\big(1 + a(t' - t)\big).$$

No. IV. — p. 22.

Constitution of the Atmosphere.

Dumas and Boussingault analyzed atmospheric air by fixing its oxygen on copper, which was weighed; the azote was also collected and weighed.

1000 parts of air at Paris contained by weight: —

	Oxygen.	Azote.
April 27, fair weather, . .	229.2	770.8
" " " " . . .	229.2	770.8
" 28, " " . . .	230.3	769.7
" " " " . . .	230.9	769.1
" 29, " " . . .	230.3	769.7
" " " " . . .	230.4	769.6
May 29, rainy, . . .	230.1	769.9
July 20, mid-day, rainy, . .	230.5	769.5
" 21, midnight, clear, . .	230.0	770.0
" 26, mid-day, clear, . .	230.7	769.3
Mean, ...	230.2	769·8
By volume, ...	208	792 = 1000

[See Page 53.]

Consumption of Oxygen and Formation of Carbonic Acid.

From experiments of Dumas on himself, it appears that about twenty cubic inches were received into the lungs at each inspiration, and from fifteen to seventeen inspirations per minute. The expired air contained from three to four per cent. of carbonic acid, and had lost from four to six per cent. of oxygen. These *data*, for each day of twenty-four hours, give,

16 insp. × 20 cubic inches = 320 cubic inch. expired per minute.
19,200 " " hour.
460,800 " " day.

Admitting as a mean 4 per cent. of carbonic acid, we have

768	cub. inch. carbonic acid per hour.	
18,432	" "	day.

Transformed into weights, we have

2,572 grains of carbon burnt per day.
857.5 gr. of carbon which represent hydrogen burnt per day.

3,429.5 total of carbon burnt in 24 hours.

This would be about 139 grains of carbon per hour, or its equivalent of hydrogen.

Mr. C. F. Coathupe, in the Reports of the British Association, 1839, arrives at precisely the same results.

Andral and Gavarret on Carbonic Acid.

Result of 75 experiments on 36 males and 26 females.

The following table shows the amount of carbon burnt by males of the following ages.

Age in years.	Carbon expelled hourly. Troy grains.
8,	77
15,	133
16,	166
18 to 20,	175
20 to 30,	188
30 to 40,	188
40 to 60,	157
60 to 80,	141
102,	91

No. V. — p. 37.

Weights of Watery Vapor in one cubic Foot of Air, at Dew-points from 0° to 100° Fahrenheit.

Degrees Fahrenheit.	Grains in a foot.	Degrees Fahrenheit.	Grains in a foot.	Degrees Fahrenheit.	Grains in a foot.	Degrees Fahrenheit.	Grains in a foot.
0	0.186	26	1.915	51	4.382	76	9 523
1	0.810	27	1.986	52	4.524	77	9 813
2	0 836	28	2.054	53	4.671	78	10.111
3	0.864	29	2.125	54	4.822	79	10 417
4	0.893	30	2.197	55	4.978	80	10.732
5	0.925	31	2.273	56	5.138	81	11.055
6	0.957	32	2.350	57	5.303	82	11.388
7	0.992	33	2.430	58	5.473	83	11.729
8	1.028	34	2.513	59	5.648	84	12.079
9	1.065	35	2.598	60	5.828	85	12.439
10	1.103	36	2.686	61	6.013	86	12.808
11	1.143	37	2.776	62	6.204	87	13.185
12	1.184	38	2.870	63	6.400	88	13.577
13	1.226	39	2 966	64	6.602	89	13.977
14	1.270	40	3.066	65	6.810	90	14.387
15	1.315	41	3.168	66	7.024	91	14.809
16	1.361	42	3.274	67	7.243	92	15.241
17	1.409	43	3.382	68	7.469	93	15.684
18	1.459	44	3.495	69	7.702	94	16 140
19	1.510	45	3 610	70	7.941	95	16.607
20	1.563	46	3.729	71	8.186	96	17.086
21	1.618	47	3.851	72	8.439	97	17.577
22	1.674	48	3.979	73	8.699	98	18.081
23	1.733	49	4.109	74	8.966	99	18.598
24	1.793	50	4.244	75	9.241	100	19.129
25	1.855						

No. VI. — p. 41.

Dalton's Table of the Force of Vapor, from 32° to 80°.

Temperature.	Force of vapor in inches of mercury.	Temperature.	Force of vapor in inches of mercury.	Temperature.	Force of vapor in inches of mercury.
32°	0.2000	49°	0.3483	65°	0.6146
33	0.2066	50	0.3600	66	0.6355
34	0.2134	51	0.3735	67	0.6571
35	0.2204	52	0.3875	68	0.6794
36	0.2277	53	0.4020	69	0.7025
37	0.2352	54	0.4171	70	0.7260
38	0.2429	55	0.4327	71	0.7507
39	0.2509	56	0.4489	72	0.7762
40	0.2600	57	0.4657	73	0.8026
41	0.2686	58	0.4832	74	0.8299
42	0.2775	59	0.5012	75	0.8581
43	0.2866	60	0.5200	76	0.8873
44	0.2961	61	0.5377	77	0.9175
45	0.3059	62	0.5560	78	0.9487
46	0.3160	63	0.5749	79	0.9809
47	0.3264	64	0.5944	80	1.0120
48	0.3372				

No. VII. — p. 45.

To determine the dew-point, take two thermometers, the scales of which agree, cover the bulb of one with thin muslin, and wet it with water; swing both thermometers in the air, that they may be exposed under similar circumstances, and note the height of the mercurial column in each, after it has become stationary. Ascertain the difference between the heights of the two columns. In the following table, find a number at the top corresponding to the difference of heights, and in the left hand column the degree answering to the temperature indicated by the dry bulb thermometer; the figure at the intersection of the two lines is the dew-point.

Suppose, for instance, the dry-bulb indicated 70°, and the wet bulb 61°; 70 — 61 = 9, which is found at the top of the table; in the column beneath, and against 70°, is 55°, the dew-point.

Table for ascertaining Dew-point by

Temp. of air.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
90°	88.7	87·5	86.3	85.1	83.8	82 5	81.2	79.9	78.6	77.2	75.8	74.4	73.0	71.5
89	87.7	86.5	85.3	84 0	82.7	81 4	80.1	78.8	77.4	76.0	74.6	73.2	71.8	70.3
88	86.7	85.5	84.3	83.0	81.7	80.4	79.1	77.7	76.3	74.9	73.5	72.1	70.6	69.1
87	85.7	84.5	83.2	81.9	80.6	79.3	78.0	76 6	75.2	73.8	72.4	70.9	69.4	67.9
86	84.7	83.5	82.2	80.9	79.6	78.2	76.9	75.5	74 1	72.7	71.2	69.7	68.2	66.6
85	83.7	82.4	81.1	79.8	78.5	77.2	75.8	74.4	73.0	71.5	70.0	68.5	67.0	65.4
84	82.7	81.4	80.1	78.8	77.5	76.1	74.7	73.3	71.8	70.4	68 9	67.3	65.7	64.1
83	81.7	80 4	79.1	77.8	76.4	75.0	73.6	72.2	70.7	69.2	67.7	66.1	64 5	62.8
82	80.7	79.4	78.1	76.7	75.3	73.9	72.5	71.0	69.6	68.1	66.5	64.9	63.2	61.5
81	79.7	78.3	77.0	75.6	74.2	72 8	71.4	70.0	68.4	66.9	65.3	63.7	62.0	60.3
80	78.6	77·3	76.0	74 6	73.2	71.7	70.3	68.8	67.2	65.7	64.1	62.4	60.7	58.9
79	77.6	76.3	75.0	73.5	72.1	70.7	69.2	67.6	66.1	64.5	62.8	61.1	59.4	57.6
78	76.6	75.3	73.9	72.5	71.0	69 5	68.0	66.5	65.0	63.3	61.6	59.8	58.1	56.2
77	75.6	74.2	72.8	71.4	69.9	68.4	66.9	65.3	63.7	62.1	60.3	58.5	56.7	54.8
76	74.6	73.2	71.8	70.3	68.9	67.3	65 8	64.2	62.5	60.8	59.1	57.2	55.3	53.4
75	73.6	72.2	70.7	69.2	67.7	66.2	64.6	63.0	61.3	59.5	57.7	55.9	54.0	52.0
74	72.6	71.1	69.7	68.2	66.6	65.1	63.4	61.8	60.1	58.3	56.4	54.5	52.5	50.4
73	71.5	70.1	68.6	67.1	65.5	64.0	62.3	60.6	58.8	57.0	55.1	53.1	51.1	49.0
72	70.5	69.1	67.5	66.0	64 4	62.8	61.1	59.3	57.5	55.7	53.7	51.7	49.6	47.3
71	69.5	68.0	66.5	64.9	63.3	61.6	59.9	58.1	56.2	54.4	52.4	50 3	48.1	45.7
70	68.5	67.0	65.4	63.8	62.2	60.5	58.7	56.9	55.0	53.0	51.0	48.8	46.5	44.1
69	67.4	66.0	64.3	62.7	61.0	59.3	57.5	55.6	53.7	51.6	49.5	47.3	44.9	42.4
68	66.4	64.9	63.2	61 6	59.9	58.1	56 3	54.3	52.3	50.2	48.0	45.7	43.2	40.5
67	65.4	63.8	62.2	60 5	58.7	56.9	55.0	53.0	51.0	48.8	46.5	44.1	41.5	38.8
66	64.4	62.7	61.1	59.3	57.5	55.7	53.7	51.7	49.6	47.3	45.0	42.4	39.7	36.8
65	63.3	61.7	60.0	58 2	56.4	54.5	52 5	50.4	48.2	45.8	43.4	40.7	37.9	34.8
64	62.3	60.6	58.9	57.1	55.2	53.2	51.2	49.0	46.7	44.3	41.7	39.0	36.0	32.7
63	61.3	59.6	57.8	55 8	54.0	52 0	49.8	47.6	45.1	42.7	40.1	37.1	34.0	30.5
62	60.3	58.5	56 7	54.8	52.8	50.7	48.5	46 2	43.7	41.1	38.3	35.2	31.9	28.2
61	59.2	57.4	55.5	53.6	51.5	49 4	47.1	44.7	42.2	39.4	36 4	33.2	29.7	25.7
60	58.2	56.3	54.4	52.4	50.3	48.1	45.7	43.2	40.6	37.7	34.6	31 1	27 3	23.0
59	57.2	55.3	53.3	51.2	49.1	46.8	44 3	41.7	39.0	35 9	32 6	28.9	24 8	20.1
58	56.1	54.2	52.2	50.0	47.8	45 4	42.9	40.1	37.2	34.0	30.5	26.6	22 1	17.0
57	55.1	53.1	51.0	48.8	46.5	44.0	41.4	38.5	35.5	32.1	28.3	24.1	19.2	13.5
56	54.0	52.0	49.8	47.6	45.2	42 6	39.8	36.8	33.6	30.0	26.0	21.4	16 1	9.5
55	53 0	50.8	48.6	46.3	43.8	41.1	38.2	35 1	31 8	27.8	23.4	18.4	12.4	4.9
54	51.9	49.7	47.5	45.0	42 4	39.6	36.6	33.3	29.7	25 6	20.8	15.3	8.5	–0.2
53	50.9	48.6	46.2	43.8	41.1	38.1	34.8	31.3	27.4	23.0	17.8	11.5	3.7	
52	49.8	47.5	45.1	42.4	39.6	36.6	33.2	29.7	25.3	20 5	14.8	7.8	–1.4	
51	48.8	46.4	43.8	41.1	38.2	35.0	31.4	27 4	22.9	17.7	11.3	3 3		
50	47.7	45.2	42.6	39.7	36.6	33.3	29 5	25.3	20.4	14.7	7.4	-2.0		
49	46.6	44.1	41.3	38.4	35.1	31.6	27 5	23.0	17.7	11.2	2.9			
48	45 5	42.9	40.0	37.0	33.5	29.7	25.5	20.6	14.7	7.3	–2.4			
47	44.4	41.7	38.7	35 5	31.9	27.9	23.3	17.9	11.4	3.1				
46	43.4	40.5	37.4	34.0	30.1	25.7	20.8	14.8	7 4	–2.6				
45	42.2	39.3	36.1	32.5	28 4	23.9	18.5	12.0	3 6					
44	41.1	38.1	34.7	30.9	26 2	21.7	15.8	8.5	–1 2					
43	40 1	36.8	33.2	29.3	24.7	19 4	12 9	4.6	–7.0					
42	38·9	35 6	31.8	27.6	22.7	16.9	9.7	0.2						
41	37.8	34.3	30.3	25.8	20.6	14 3	6.2	–5.0						
40	36.7	33.0	28.8	23 9	18.1	11 4	2.2							

Observations on the Wet and Dry Bulb Thermometer.

Temp. of air.	15	16	17	18	19	20	21	22	23	24	25	26	27	28
90°	70.0	68.4	66.8	65.2	63.6	61.9	60.1	58.3	56.4	54.4	52.4	50.3	48.0	45.6
89	68.8	67.2	65.6	63.9	62.2	60.5	58.7	56.9	54.9	52.9	50.8	48.5	46.2	
88	67.5	65.9	64.3	62.6	60 9	59.1	57.2	55 3	53.3	51.2	49.0	46.7	44.3	
87	66.3	64.7	63.0	61.3	59.5	57.7	55.8	53.8	51.7	49.6	47.3	44.9	42.4	
86	65.0	63.3	61.6	59.9	58.1	56.2	54.2	52.2	50.1	47.8	45.5	43.0		
85	63.7	62.0	60.3	58.5	56.6	54.7	52.7	50 6	48.4	46.1	43.6	41.0		
84	62.4	60.7	59.0	57.1	55.2	53.2	51.1	48.9	46.6	44.2	41.6	38.9		
83	61.1	59.4	57.5	55.6	53.7	51 6	49.5	47.2	44.8	42.3	39.6			
82	59.8	58.0	56.1	54.2	52.1	50.0	47.8	45 4	43.0	40.3	37.4			
81	58.5	56.6	54.7	52.7	50.6	48.4	46.1	43.6	41.0	38.2	35.2			
80	57.1	55.2	53.2	51.1	49.0	46.7	44.3	41.7	39.0	36.0				
79	55.7	53.7	51.7	49.6	47.3	45.0	42.4	39.7	36.8	33.7				
78	54.2	52.2	50.1	48.0	45.6	43.1	40.4	37.6	34.6	31.2				
77	52.8	50.7	48.5	46.2	43.8	41.2	38.4	35.4	32.2					
76	51.3	49.2	46.9	44.5	42.0	39 2	36.3	33.1	29.7					
75	49.8	47.6	45.2	42.7	40.1	37 2	34 1	30.7	27.0					
74	48.2	46.0	43.5	40.8	38.1	35.0	31.7	28.1						
73	46.6	44.2	41.6	39.0	36.0	32.8	29.2	25.3						
72	45.0	42.5	39.8	36.9	33.8	30.4	26.5	22.3						
71	43.3	40.6	37.8	34.8	31.4	27.8	23.7							
70	41.5	38.7	35.8	32.5	29.0	25.0	20.5							
69	39.7	36.8	33.6	30.2	26.3	22 0	17.1							
68	37.8	34.7	31.4	27.7	23.5	18 8								
67	35.8	32.5	29.0	25 0	20.4	15.1								
66	33.7	30.2	26.4	22.1	17.0									
65	31.5	27.8	23.6	18.8	13.2									
64	29.2	25.2	20 6	15.3										
63	27.6	22.3	17.3	11.4										
62	24.0	19.3	13.7											
61	21.2	15.9	9.6											
60	18.1	12.2												
59	14.6	7.9												
58	10.8													
57	6.4													

No. VIII. — p. 62. *A Table of the Analyses of Confined Air.*

Places in which the air was collected.	Oxygen in 1000 parts.	Carbonic acid in 1000 parts.	Capacity of room.	Number of persons.	Duration of closing or remaining in room.	Vol. of air for each person for length of time.	Vol. of air for each person per hour.	
	dry air.	dry air.	cub. m.		h. m.	cub. m.	cub. m.	
I. Serre de Buffon, Garden of Plants (evening).	230.1		273.7		12			Tropical plants. Exposed to sun two thirds of day.
II. Serre de Buffon, Garden of Plants (morning).	229.6	0.1	273.7		24			Air taken next morning at 8 o'clock. Feb. 10, 1842.
III. Amphitheatre of Chemistry, Sorbonne, before lecture.	224.3	6.5	1000.0	400?	30			Commencement of M. Dumas's lecture. Doors closed with springs.
IV. The same, after lecture.	219.6	10.3	1000.0	900	1 30	1.1	0.74	End of Dumas's lecture.
V. Bedchamber (morning).	229.4	0.4	81.0	2	8	40.5	5.0	Air collected one metre above floor in winter. Chimney in room.
VI. Ward in Notre Dame du Rosaire à la Pitié (Females).	229.1	0.8	1958.0	54	2 30	36.0	4.0	9 A. M., 2½ hours after closing windows.
VII. The same.	227.2	2.8	1958.0	54	9	36.0	4.0	6 A. M. Two stoves, combustion feeble during night. Air taken 1.5 metres above floor.
VIII. Flat-roofed dormitory, Salpêtrière (Incurables).	225.2	8.0	611.1	55	8 15	11.1	1.4	Doors and windows closing badly. Air taken at 0.60 metres above floor. Odor sensible.
IX. Dormitory Salpêtrière (Epileptics).	226.0	5.8	2417.0	121	9	19.9	2.2	Doors and windows closing better. Odor sensible. Air taken 0.60 metres.
X. Ward of Asylum (Préau).	227.1	2.7	230.0	116*	3			Odor disagreeable. Door half open.
XI. Primary School-room, fully ventilated.	228.4	lost.	721.0	180†	4			No appreciable odor. 1080 cubic metres escaping hourly through ventilators.
XII. The same, ill ventilated.		4.7	721.0	180	4			No sensible odor. 837 cubic metres escaping hourly.
XIII. The same, entirely closed.		8.7	721.0	180	4	3.1	0.77	All apertures closed. Sensation of heat, accelerated respiration. Internal temperature, 18° C.; external, 16° C.
XIV. Chamber of Deputies, ventilating-flue.		2.5	5000.0	600	2 30			No odor. 11,000 cubic metres hourly escaping through ventilator.
XV. Opéra Comique, Pit.		2.3	5000.0	1000	2 30			Air taken at stage. 80,000 cubic metres hourly escaping by ventilator.
XVI. Opéra Comique, Boxes.		4.3	5000.0	1000	2 30			Air taken at ceiling.
XVII. Stable, closed.	222.5	1.05	339.5	9‡	7 45	37.7	4.7	Doors and windows closing badly.
XVIII. Stable, ventilated.	229.2	2.2	2980.0	57‡	8	52.2	6.5	Area of section for entrance of air, 3 square metres.

* Boys and girls from 3 to 16 years. † Boys from 7 to 10 years. ‡ Horses.

No. IX. — p. 70.

Composition of Tallow, Wax, Oil, and Carburetted Hydrogen.

	Carbon.	Hydrogen.	Oxygen.
Tallow, . .	79.09	11.16	9.75
Wax, . .	81.75	13.67	4.55
Whale Oil, . .	68.87	15.03	16.10
Carburetted Hydrogen,	75	25	

To estimate the quantity of carbon in a given quantity of oil, we first get the weight in grains of a cubic inch of the combustible, which, for whale-oil, estimating its specific gravity at .923, will be 227 grains; one fluid dram is 0.226 of a cubic inch; hence a fluid dram weighs $227 \times 0.226 = 51.3$ grains, of which 68.8 per cent., or 35 grains, is carbon. Carbonic acid is composed of 6 parts of carbon for every 22 of acid; $35 \div 6 \times 22 = 127$ grains of carbonic acid; 100 cubic inches of carbonic acid weigh 47.262 grains; 127 grains equal 254 cubic inches.

A cubic foot of carburetted hydrogen weighs 294 grains, of which three quarters, or 220.5 grains, are carbon, and one quarter, or 73.5 grains, are hydrogen. From these data the quantity of carbonic acid is readily obtained, as in the preceding case.

No. X.—p. 70.

Comparative Value and Cost of Light.

M. Péclet's Table reduced to English Measures and Weights. Cost of Oil estimated at $1.12 per Gallon.

Nature of Light.	Intensity.	Consumption per hour in grains.	Cost of Light. Cents per Pint.	Cents per Hour.
Mechanical Lamp, ...	100.00	651.0	14	1.4
Flat-wick Mechanical Lamp, .	12.05	170.0	14	0.4
Hemispherical Dome Lamp, . .	31.00	413.0	14	0.84
Sinumbra Lamp, . . .	85.00	666.0	14	1.4
" " with a lateral fountain or vase,	41.00	279.0	14	0.57
" " with a fountain above,	90 00	666.0	14	1.41
Girard's Hydrostatic Lamp, . .	63.66	538.0	14	1.12
Thilorier's or Parker's Lamp, .	107.66	791.0	14	1.68
Two-wicked Hand Lamp, ¼ inch tube,		102.6	14	0.22
Argand Lamp, ¾ inch wick, . .		513.0	14	1.1

No. XI.—p. 70.

Dr. Ure's Table of Relative Consumption and Value of Candles.

No. in a Pound.	Duration of a Candle. h. m.	Weight in Grains	Consumption per hour in Grains.	Proportion of Light.	Economy of Light.	Candles equal one Argand.
10 Mould,	5 9	682	132	12.25	68.0	5.70
10 Dipped,	4 36	672	150	13.00	65.5	5.25
8 Mould,	6 31	856	132	10.50	59.5	6.60
6 "	7 2½	1160	163	14.66	66.0	5.00
4 "	9 36	1707	186	20.25	80.0	3.50
Argand Oil,			512	69.40	100.0	

No. XIII. — p. 127.

Experiments on the Cooling Effect of Windows.

These experiments were made in a wooden house, double plastered, with a space between the two plasterings ; walls 6 inches thick. Heat introduced from a hot-air furnace, heated air being shut off when the room was heated to a proper temperature. Thermometer four feet from the floor. When windows were closed, two thicknesses of blankets were fastened closely to the window-frame internally.

Three windows, equal to 33.21 square feet ; walls, 531 square feet ; cubic contents of room, 1930 feet, being 9 feet high, 16.5 feet long, 13 feet wide.

The room was kept as nearly as possible under the same circumstances.

	External Thermom.	Internal Thermom.	Time.	
	°	°	h. m.	
March 19, 1843.	26	74	9 1	weather calm, windows uncovered.
	25	64	10 15	
			74	
	22	74	11 41	windows covered with blankets.
	18	59	2 5	
			144	
March 20.	25	74	8 8	Windows uncovered.
	24½	64	9 24	
			76	
	24	74	10 17	Windows covered with blankets.
	22	61	12 22	
			125	
March 21.	24	74	8 51	Calm, windows covered.
	19	64	10 19	
			88	
	17	74	11 26	Windows uncovered, calm.
	16	64	12 16	
			50	

33*

The experiments were also made in other rooms, and with wooden shutters internally.

The results are as follows : —

1st, room cooled	10° in	74′ =	1° in	7.4′,	windows open.
" "	15° in	144′ =	1° in	9.6′,	windows closed.
2d, room cooled	10° in	76′ =	1° in	7.6′,	windows open.
" "	13° in	125′ =	1° in	9.6′,	windows closed.
3d, room cooled	10° in	88′ =	1° in	8.8′,	windows closed.
" "	10° in	50′ =	1° in	5.0′,	windows open.

Experiment with wooden shutters : —

Room cooled	10° in	93′ =	1° in	9.3′,	shutters closed.
" "	10° in	58′ =	1° in	5.8′,	shutters open.

From the above, the effect of glass is very evident, and also the advantage of curtains and shutters. We shall not attempt to form any general rule, since it could be applied correctly only under circumstances which differed very little from the above.

The preparation for covering white cotton for interior windows is composed of 4 oz. of pulverized dry white cheese, 2 oz. of white slack lime, and 4 oz. of boiled linseed oil. These three ingredients having been mixed with each other, 4 oz. of the white of eggs, and as much of the yolk, are added, and the mixture then made liquid by heating. The oil combines easily with the other ingredients, and the varnish remains pliable and quite transparent. It is applied with a brush.

No. XIV. — p. 145.

Draught of Chimneys.

Let H be the height of the chimney ; h, the difference of the heights of columns of equal weights ; g, the intensity of gravity, or 32.2 ; V the velocity of the escaping current. We have by the laws of dynamics (see Cambridge Mechanics, page 172),

$$V = \sqrt{2 g h} = 8.024 \sqrt{h};$$

or the velocity equals eight times the square root of the height, nearly.

The height h is determined by the amount of expansion gases undergo from increase of temperature. Let t be the temperature of the cold air, and t' that of the warm air; then, by the formula for the dilatation of gases (p. 379), we have

$$h = \text{H}\, a\, (t' - t)\ ;$$

and substituting this value for h we have

$$V = 8.024 \sqrt{\text{H}\, a\, (t' - t)}.$$

For example, if the column in the chimney be 30 feet, the external air be 50°, and that of the warm air be 300°, we shall have

$$V = 8.024 \sqrt{30 \times 0.00203 \times (300 - 50)} = 31.3 \text{ feet.}$$

This formula is not rigorously exact, for the generating height of the velocity is

$$\text{H}\left(\frac{1 + a\,t'}{1 + a\,t} - 1\right) = \text{H}\left(\frac{a\,(t' - t}{1 + a\,t}\right).$$

But as t, the external temperature, seldom exceeds 70°, $1 + a\,t$ is always less than 1.073, and may, consequently, without sens ble error, be taken as unity.

In the first formula, $V = \sqrt{2\, g\, h}$, g is taken in feet; consequently H, also, should be taken in feet; the velocity V represents the space passed through in one second of time.

No. XV. — p. 147.

Formulæ expressing the Resistances which diminish the Draught of Chimneys.

In the preceding formula, we have supposed that the warm air experiences no diminution of its velocity from the resistance offered by the walls of the chimney or other tube through which it passes. Experiments on the flow of fluids through tubes have shown :—

1. That the resistance is proportional to the length of the tube.

2. That the resistance is in the inverse ratio of the diameter of the tube.

3. That the resistance increases proportionally to the square of the velocity.

From these facts it is obvious that the movement of the air in a chimney must be much less than the formula given above would lead us to expect.

In the following formula, an expression for the resistance is introduced, supposing it to be the same for warm as for cold air.

Let P be the pressure upon the air of the chimney expressed in feet of warm air, or the quantity H $a\,(t - t)$; p the pressure also in warm air which produces the velocity ; H the height of the chimney ; D the diameter of the chimney ; K the coefficient of resistance ; we shall have, for a chimney completely open at the two extremities,

$$P - p = \frac{K\,H}{D} V^2 ;$$

and as $p = \frac{V^2}{2\,g}$, this expression becomes

$$P - \frac{V^2}{2g} = \frac{K\,H\,V^2}{D} ; \text{ or } V^2 = \frac{2\,g\,P\,D}{D + 2\,g\,K\,H}.$$

Péclet, who gives this formula, has made a series of experiments to determine the value of K by adapting pottery chimneys, sheet-iron chimneys, and cast-iron chimneys, of different lengths and diameters, but all circular, to the same fire-place, so arranging the fire that the grate should offer as little resistance as possible to the passage of the air. The result of these experiments

gave for K the following values: for the pottery chimney, 0.0127; for the sheet-iron, 0.005; for the cast-iron, 0.0025. The cast-iron chimney had been long used, and was coated with soot; hence the coefficient obtained for the cast-iron will probably be that for any other substance covered with soot. The pottery and sheet-iron chimneys had never been used, and did not become covered with lampblack during the experiment. The fuel used was charcoal, burning without smoke. The temperature of the chimneys was taken at the two extremities, by thermometers with their bulbs in the axis of the chimney.

The resistance is proportional to the perimeter of the section of a prismatic tube, and in the inverse ratio of the surface; but as the relation of the perimeter to the surface is the same for the circle and the circumscribed square, the formula will answer also for square chimneys, of which the side of the square is equal to the diameter of the circle. The greater the difference between the sides of a parallelogram, the greater the resistance.

Influence of the Length and Curvature of Tubes. It was found, by placing upon the furnace just mentioned tubes of different curvatures, that the observed velocities did not differ greatly from those obtained by calculation from the following equation: —

$$V^2 = \frac{2 g P D}{D + 2 g K L};$$

in which P is equal to H $a\ t$, as in the preceding equation, and L represents the length of the tube. From this we should infer that changes of direction made no appreciable difference.

If a circuit be composed of a length, L, traversed by warm air, and another circuit, L′, traversed by cold air, and we designate by δ the density of cold air relatively to warm air, we shall have, since the coefficient of resistance is independent of the density of the gas,

$$P - \frac{V^2}{2 g} = \frac{K L}{D} V^2 + \frac{K L'}{D \delta^2} V^2.$$

The experiments of D'Aubuisson on the flow of cold air, under constant pressure through tubes, lead to the conclusion, that, when a chimney is contracted at the top, the velocity of the air in the contracted portion is increased, and that it continues to increase with the diminution of the aperture, until it is equal to that which would have taken place had the air experienced no resist-

ance from the sides of the flue. The reason of this seems to be, that, with the contraction of the chimney-top, the velocity of the air in the chimney is diminished, and with the diminished velocity the resistance diminishes much more rapidly, until it reaches a limit at which it becomes inappreciable in practice.

To obtain an algebraical expression for the velocity of escape, let S be the section of the chimney, s the area of the aperture, φ the coefficient of the contraction of the vein, which coefficient varies according as the orifice is in a thin plate, a short cylinder, or a conical tube, v the velocity; the other letters represent the same quantities as in the former equations. The velocities being in the inverse ratio of the sections, since the same volume of gas must pass during the same instant through any horizontal area, we shall have

$$P - \frac{v^2}{2g} = \frac{K\,H}{D} \cdot \frac{s^2 \varphi^2}{S^2} v^2; \quad \text{or} \quad v^2 = \frac{2\,g\,P\,D\,S^2}{D\,S^2 + 2\,g\,K\,H\,s^2\,\varphi^2}.$$

Substituting for K in this equation the values belonging to the different chimneys, according as they are of brick, sheet iron, or cast iron, and for φ the following values, —

0.65 for an orifice in a thin plate,
0.93 for a short cylindrical tube,
0.95 for a short conical tube, —

we shall have formulæ applicable to all cases.

If the coefficient of contraction be taken as unity, as it may be in all apertures in practice, we have

$$v^2 = \frac{2\,g\,P\,D\,S^2}{D\,S^2 + 2\,g\,K\,H\,s^2}.$$

If we make S, the section of the chimney, very large compared with s, we may neglect the quantities $2\,g\,K\,H\,s^2$; for the resistance would then become inappreciable, and the equation becomes

$$v = \sqrt{2\,g\,P}.$$

The velocity in a chimney contracted at the top may be compared with that in a chimney of the same height, having throughout the same diameter as the orifice. Designating by v' the velocity in the latter chimney, we shall have

$$\frac{v}{v'} = \sqrt{\frac{D\,S^2\,(2\,g\,K\,H + d)}{d\,(D\,S^2 + 2\,g\,K\,H\,s^2)}}.$$

If, as before, we suppose S very great compared with s, we may neglect $2 g \mathrm{K} \mathrm{H} s^2$, and the expression becomes

$$\frac{v}{v'} = \sqrt{1 + \frac{2 g \mathrm{K} \mathrm{H}}{d}}.$$

This expression represents the maximum of the ratio $\frac{v}{v'}$. But to obtain it, it is not necessary to make S very large compared with s; for when we increase the ratio of the sections S to s, that of the velocities v to v' increases at first rapidly, and afterwards very slowly, a direct result of the last expression. For example, suppose a brick chimney 10 yards high, and suppose $d = 0.20$, the maximum of the ratio of v to v' given by the last formula is 3.53; and by giving successively the values 2, 3, 4, 5, to the ratio $\frac{\mathrm{S}}{s}$ we have for $\frac{v}{v'}$, 3.07, 3.42, 3.52, 3.53. Hence, giving to the chimney two or three times the area of the orifice, we obtain very nearly the maximum of effect. This is an important practical rule. See page 148.

If the air supplying the fire is cold, and traverses a canal of the same diameter as the chimney, before entering the fire-place; by designating the length of the circuit by L, and neglecting the influence of variations of velocity resulting from variations of temperature, we shall have

$$v^2 = \frac{2 g \mathrm{P} \mathrm{D} \mathrm{S}^2}{\mathrm{D} \mathrm{S}^2 + 2 g \mathrm{K} \mathrm{L} s^2}.$$

If we suppose the diameter of the whole canal such that the velocity of the air is insensible, the superior orifice remaining constant, we shall find for the ratio of v to v' of the velocity in the second case to the velocity in the first

$$\frac{v}{v'} = \sqrt{1 + \frac{2 g \mathrm{K} \mathrm{L}}{d}}.$$

Velocity of Warm Air in a Chimney contracted at the Base. — The results of many experiments made on the influence of contractions and enlargements in chimneys lead to the following conclusions.

1. In a canal traversed by air, the loss of moving height (or head, as it is termed, when applied to water) caused by a contraction is much less than the height which corresponds to the difference of velocities in the contraction and beyond it.

2. The true loss is a little greater than the difference of heights corresponding to the velocities multiplied by the ratio of the surface of the orifice to the surface of the canal beyond the contraction.

3. A sudden enlargement in a canal, at least to a certain extent and within certain limits, has little influence.

The following equations have been constructed to express the velocity of escape at the summit of a chimney. The velocities deduced from the first equation will be smaller than the true velocities, and those deduced from the second will be somewhat larger; the latter are nearer the truth than the former. The same notation is preserved as in the preceding equations.

$$v^2 = \frac{2\,g\,P\,D\,s^2}{D\,s^2 + 2\,g\,K\,H\,s^2 + D\,(S - s)^2}\ ;\ \text{and}$$

$$v^2 = \frac{2\,g\,P\,D\,S\,s^2}{S\,s^2\,(D + 2\,g\,K\,H) + D\,s\,(S^2 - s^2)}\ .$$

When S is much larger than s, we may neglect in the denominator of the first equation the terms which contain s; and it will become

$$v^2 = \frac{2\,g\,P\,s^2}{S^2}\ ;$$

and the velocity in the orifice will be

$$v'^2 = 2\,g\,P.$$

On the supposition upon which this equation is constructed, if we increase the diameter of a chimney of which the inferior opening remains constant, the velocity in this inferior opening will increase until it reaches that which is due to the height of the column of warm air. We gain, then, by increasing the diameter, that portion of the moving height which corresponds to the resistances in the chimney. This is effected practically by making the diameter of the chimney three or four times that of the inferior opening; for the resistances being proportional to the square of the velocities, they diminish very rapidly as the diameter increases.

From the second equation, which is much nearer the truth than the first, the velocities in the opening go on increasing indefinitely in proportion as the diameter of the chimney increases, and this velocity may even become greater than that due to the height of the column of warm air. This is verified by experiment. The

velocity in one instance due to the height was 10.73; the velocity observed at the superior part was .81, when the surface of the diaphragm was equal to .0006; now, as the section of the chimney was .0314, the velocity in the opening was $\frac{.81 \times .0314}{.0006} = 42.39$, a velocity nearly four times greater than that due to the height.

The increase of velocity in the inferior opening would be still greater, if the section of the chimney increased gradually from the edges of the opening until it attained the full size of the flue; for, under such circumstances, there is no loss of moving power in consequence of change of velocity; the only loss is that due to resistance.

This influence of the enlargement of the chimney on the draught has a very important bearing on ventilating-flues, for it enables us, with the same amount of heat, to overcome very considerable resistances, or, what is the same thing, produce the same effect with a less quantity of fuel.

If the lower opening of the chimney communicates with an air-trunk, as it must do in ventilating arrangements, the velocity of escape, supposing the air experiences no other resistances than those we have now considered, may be calculated by the formula

$$P - \frac{v^2}{2g} = v^2 (A + B + C);$$

in which A represents the resistance in the air-channel, B the loss of height due to change of section in the channel, and C the resistance in the chimney. Supposing the air-channel and the chimney square or circular, the quantities A and C would take the form

$$\frac{K L v'^2}{D};$$

K being the coefficient of resistance, L the length of the air-channel, D its diameter or side, and v' the velocity of the air. From these the velocities are easily calculated.

Of the Form of a Chimney. — When air moves through a prismatic canal, of any form whatever, the particles next the circumference of the canal experience a certain resistance, which is transmitted to the other neighbouring particles; hence arises a constant retarding force, proportional to the surface of the chan-

nel, the square of the velocity, and in the inverse ratio of the section. This force will be represented by

$$\frac{K' C H v^2}{S};$$

in which K′ represents a constant number, C the circumference of a section of the prism, S its surface, H the length, and v the velocity of the escaping air.

From this it is obvious that the circle is the best form for a chimney, since it has the greatest area with the least circumference; and next to this, of four-sided figures, the square. The more we depart from these forms, the greater the resistance.

The preceding formulæ are those given by Péclet, in his treatise on the application of heat, to which the reader is referred for a more full examination of this subject.

It must be observed, however, that this subject is extremely difficult, and that the results of these equations must be taken as approximations merely.

Several mathematicians have considered the question of chimney draughts, but the conclusions to which they have come exhibit very great discrepancies. The cases to which these formulæ were applied were the following.

A room is to be ventilated by an opening in its ceiling; it is a double cube of 27 feet, with doors 7 feet high, from which, taking the half-height of the door as the average entry of the air, the height of the column of air will be $27 - 3.5 = 23.5$ feet. Temperature of the room, 60°; temperature of the external air, 40°. The velocity of the air in the opening in the ceiling is required.

A furnace with a chimney, the top of which is 40 feet above the average height of the opening to admit the air. Temperature of smoke issuing from the flue of the chimney, 120°. External temperature, 40°.

The following table gives the velocity of the ascending currents, as calculated by the different formulæ.*

* The Theory and Practice of Warming and Ventilating, by an Engineer, p. 172.

	Ventilation of chamber per second.	Draught of furnace per second.
Montgolfier, ...	8.32	13.91
Sylvester, in Rees's Cyclopædia, . .	0.78	1.94
Mr. Gilbert, Quarterly Journ. of Science, 1822,	7.88	225.67
Sylvester, in Annals of Philosophy, .	1.61	7.73
Tredgold, ...	4.8	9.5

The following table exhibits the comparative results of experiment and calculation. The stove upon which the experiments were made was of the ordinary kind, with a wrought-iron pipe, four or five inches in diameter, and forty-five feet high; fuel, good charcoal. The velocity was observed by noting with a stop-watch the ascent of a puff of smoke from a little tow dipped in oil of turpentine and thrust quickly into the fire. External temperature, 68°.

Trials.	By theory.	By experiment.	By Péclet's formula.	Mean temperature of chimney.
1	26.4 feet,	5.00 feet,	5.90	190
2	29.4 "	5.76 "	6.45	214
3	34.5 "	6.30 "	7.61	270

The first theoretical velocity is given by Dr. Ure, with the experiments; the second I have calculated by the following formula: —

$$v^2 = \frac{2gPD}{D+2gKH}.$$

No. XVI. — p. 149.

Table of Draught of Chimneys at different Temperatures. External Air, 32°.

Temp. of warm air.	Draught.	Temp. of warm air.	Draught.	Temp. of warm air.	Draught.
86	4.93	356	8.09	608	8.27
104	5.51	374	8.14	662	8.21
122	5.98	392	8.17	752	8.13
140	6.35	410	8.21	842	8.03
158	6.66	428	8.23	932	7.92
176	6.92	446	8.25	1022	7.80
194	7.13	464	8.26	1112	7.62
212	7.33	482	8.27	1202	7.56
230	7.48	500	8.273	1292	7.44
248	7.62	518	8.278	1382	7.33
266	7.73	527	8.279	1472	7.22
284	7.83	536	8.276	1562	7.11
302	7.92	554	8.275	1652	7.00
320	7.98	572	8.27	1742	6.90
338	8.05	590	8.26	1832	6.80

No. XVII. — p. 162.

Application of the Theory of the Centrifugal Pump to the Fan.

Let us suppose that the tube A B represents the space between any two contiguous vanes of the fan, and that it revolves about the point O as a centre. Let a = the length of the tube A B in feet, t = the time of a revolution in seconds, $g = 32.2$ feet, the measure of the force of gravity, and $\pi = 3.141593$, the circumference of a circle whose diameter is unity. Then, since the centrifugal force is as the velocity it generates in a unit of time, we shall have the centrifugal force of a particle $d\psi$ of the fluid, at the distance ψ from O, equal to $d\psi \left(\frac{2\pi\psi}{t}\right)^2 \div \psi = \frac{4\pi^2 \psi\, d\psi}{t^2}$, the integral of which is $\frac{4\pi^2 \psi^2\, d\psi}{2t^2\, d\psi} = \frac{2\pi^2\psi^2}{t^2}$ = the centrifugal motive force of

the column ψ; which, when $\psi = a$, becomes $\frac{2\,\pi^2\,a^2}{t^2}$ for the whole centrifugal motive force of the air in the tube A B. The pressure of a column, whose length is a, will vary as $g\,a$; hence it will be $g\,a : a :: \frac{2\,\pi^2\,a^2}{t^2} : \frac{2\,\pi^2\,a^2}{g\,t^2}$, which equals the length of a column of air whose pressure is equivalent to the centrifugal force, and which would expel the air from the extremity B with a force equal to that produced by the whirling motion. According to the laws of spouting fluids, air, under a constant head $\frac{2\,\pi^2\,a^2}{g\,t^2}$, would issue from the extremity B, with a velocity equal to that acquired by a heavy body falling through a space equal to this head.

$v = \sqrt{2\,g\,h}$, putting for h its value $\frac{2\,\pi^2\,a^2}{g\,t^2}$, we have $v = \sqrt{2\,g\left(\frac{2\,\pi^2\,a^2}{g\,t^2}\right)} = 8.025\sqrt{\frac{2\,\pi^2\,a^2}{g\,t^2}}$, in which the velocity of the flow varies, as the circumference, divided by the time of revolution in seconds, or as the velocity of the tips of the vanes.

No. XVIII. — p. 320.

Investigation of the Limit of Vitiation of the Air in Rooms partially ventilated.

Mr. Tredgold has given the following investigation of the limit of deterioration of the atmosphere in an occupied apartment, with a certain amount of ventilation.

"Let us suppose a room to contain such a number of persons as will generate b cubic feet of impure air, and that the ventilation is v cubic feet of air in the same time; and, under such circumstances, that a uniform mixture of the pure and impure air must take place; also let the cubic contents of the room be B feet.

"The impure air will become diffused through the space B, so as to be expanded into $\frac{B+v}{b}$ times the space it occupied when first generated; consequently, if a quantity of air $= b$ were removed, it would take away only $\frac{b^2}{B+v}$ of impure air; and as only v is to be removed by ventilation, we have

$$b : v :: \frac{b^2}{B+v} : \frac{b\,v}{B+v},$$

which equals the quantity of impure air removed in a unit of time by ventilation. After the room has been occupied by the persons for a time t, the quantity of impure air removed will be to the quantity generated in the same time, as

$$\frac{b}{m} + \frac{b\,m - b}{m^2} + \frac{(b\,m-b)^2}{m^3} + \ldots\ldots \frac{(b\,m-b)^{t-1}}{m^t} : b;$$

or, as $1 + \frac{m-1}{m} \left(\frac{m-1}{m}\right)^2 + \ldots\ldots \left(\frac{m-1}{m}\right)^{t-1} : m;$

where $m = \frac{B+v}{v}$.

" The sum of progression is

$$m \left\{ 1 - \left(\frac{m-1}{m}\right)^t \right\};$$

and substituting for m its proper value, the ratio is

$$1 - \left(\frac{B}{B+v}\right)^t : 1.$$

" Now, whatever value we give to v, it is obvious, that, in the case of complete diffusion, the whole of the impure air which enters cannot be removed, if v be less than B; for in all cases where v is less than B, the time t must be infinitely great. Hence, we shall show, that, when there is a certain degree of ventilation going on, the accumulation of irrespirable gas approaches constantly to a limit which it never exceeds; for let n represent the quantity of irrespirable gas in atmospheric air; and let $x\,n$ be the quantity to which it approaches, but is not to exceed. If it did arrive at the proportion $x\,n$, then the consumption of oxygen would be exactly equal to the supply, and consequently no further change could take place. For $\overline{1 - n\,v}$ would be the quantity of oxygen entering by ventilation, and $\overline{1 - n\,x\,v}$ the quantity let out; therefore the difference is the supply, which is equal $\overline{n\,x - n\,v}$. But the consumption in the same time is $\overline{1 - n\,b}$, and the consumption will be equal to the supply when $\overline{1 - n\,b} = n\,v\,(x-1)$, or when $x = 1 + \frac{\overline{1-n\,b}}{n\,v}$. In atmospheric air $n = \frac{4}{5}$ nearly, consequently $x = 1 + \frac{b}{4\,v}$, and a greater proportion of irrespirable air than $x\,n$ cannot accumulate. One man generates 160 cubic

inches of irrespirable air in a minute; hence $b = \frac{160}{1723} = \frac{1}{10.8}$; or $x = 1 + \frac{1}{43.2\,v}$.

"The space allotted to one man in a hospital or in a prison is about 600 cubic feet, and suppose the ventilation to be one cubic foot per minute, then $v = 1$ and $x = 1.023$, or the quantity of irrespirable air will increase $\frac{1}{43}$ part, but never exceed that proportion. But with the ventilation of 4 cubic feet of air for each individual, the increase cannot exceed the $\frac{1}{172}$ part, even when the ventilation is conducted on the most defective principles; and it certainly ought to be a nice experiment to judge of the increase of $\frac{1}{172}$ part, considering the nature of the operation; and we have shown that it would require an unlimited time to arrive at that degree of excess.

"The accumulution of carbonic acid may also be considered in the same manner; its proportion in atmospheric air is stated to be $\frac{1}{1000}$ part; and

$$1 + \frac{1000\,b\,(1-n)}{v} = x; \text{ or } 1 + \frac{18.52}{v} = x.$$

Consequently, with a ventilation of one cubic foot per minute, the proportion of carbonic acid will increase to about $\frac{1}{50}$ part of the air of the room, but will not exceed that proportion. If the ventilation be 4 four cubic feet per minute, the proportion cannot exceed $\frac{1}{200}$ part of the air, even in the most unfavorable circumstances."

No. XIX.

Velocity of Air in Air-tubes, House of Representatives, Boston.

Two iron tubes, 14 inches in diameter, have been placed in the dome of the State House, connected with the ceiling of the House, and terminating with a turn-cap at a level with the top of the lantern.* Whole length of the pipe 69 feet, 20 feet of

* Two tubes have been added since these observations were made.

which are external to the dome. Height of the ceiling of the Representative's Chamber, 46 feet. The chamber is heated by hot-air furnaces in the cellar, 34 feet below the level of the floor of the chamber. A series of observations was made in the month of March, 1843, to determine the velocity of the current, and also to test the accuracy of the water-oil barometer used by Dr. Ure in his comparison of the revolving fan and the draught of chimneys. In our hands, we were satisfied that the indications of the barometer were not to be depended upon. The viscosity of the oil varied much with different temperatures, and the water was very liable to escape into the cisterns, from which it could not readily be removed. To ascertain the velocity, holes were bored in the tube, one near the floor of the dome, and another exactly 40 feet above. Small portions of down were detached at the lower opening, and their transit noted at the upper. By this means, half seconds were readily observed. The thermometer, placed in the tube, was between 69° and 74°, according to the number in the chamber.

March 3. Number of persons from 550 to 600; strong wind; thermometer 74°; velocity of down, 40 feet in $3'' = 13.3$ feet.

Feb. 28. No wind; thermometer, 69°; velocity, 40 feet in $4' = 10$ feet. Strong wind; thermometer, 63°; velocity, 40 feet in $3'' = 13.3$.

Area of tubes, 154 square inches; hence 1 foot in length contained 1.07 cubic feet. Velocity of 13 feet per second delivers 13.91 cubic feet, $13.91 \times 2 = 27.82$ cubic feet for both tubes; 1668 cubic feet per minute. This is equal to about $2\frac{4}{5}$ cubic feet for each person per minute. The odor of the chamber, especially in the galleries, invariably unpleasant. Two and a half seconds was the shortest, and four seconds the longest, time observed; but it was found that the wind produced a decided effect, when blowing strongly. And this we attribute to the fact, that the opening connected with the furnace, through which all the air passed, was on the northwest (the windward) side of the State House; consequently, the air was thrown into the furnace with considerable force.

INDEX.

INDEX.

E.

F.

G.

I.

J.

L.

M.

T.

W.

Wyman, Morrill, 1812-1903.
A practical treatise on ventilation: by Morrill Wyman. Cambridge, Metcalf and Company, 1846.
xvi, 419 p. illus. 20 cm.